Cell site analysis; use and reliability of survey methods

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Original citation & hyperlink:

Tart, MS, Brodie, I, Patrick-Gleed, N, Edwards, B, Weeks, K, Moore, R & Haseler, R 2021, 'Cell site analysis; use and reliability of survey methods', Digital Investigation, vol. 38, 301222. https://doi.org/10.1016/j.fsidi.2021.301222

DOI 10.1016/j.fsidi.2021.301222
ISSN 2666-2817

Publisher: Elsevier

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1 Abstract

An RF Survey may form part of a wider forensic strategy. The purpose of a survey within this strategy, and the manner in which survey data may be used to better inform evaluative or investigative opinion, is discussed. Hazards of using survey results in isolation of other information to produce a series of piecemeal technical observations (in isolation of each other and the wider purpose of the examination) are explored. Technical issues concerning measuring a complex radio environment, and methods to address those issues, are presented. Experiments comparing CDR ("ground truth" data) from a known location is compared to survey measurements focussed on that location. The performance of methods using engineering handset survey devices (Anite Nemo) is compared with that of Software Controlled Radio (QRC ICS-500) for these trial data. Assessments of uncertainty within the methods tested are made, including accuracy, precision and reliability.

2 Introduction

2.1 Cell Site Analysis is the process of assessing whether a given set of CDRs (variously defined as Call Data Records, Call Detail Records and Charging Data Records in different ETSI standards):

- Would be expected given one or more propositions (usually set by Prosecution and/or defence)
- Can provide insight as to user activity (e.g. movement or presence at possible locations) in the absence of propositions

These approaches are different, and require different modes of thinking of a practitioner [ref 1]

2.2 The cell used (and the cellsite on which the cell was based) by a mobile device at the time of signalling activity is often included in the call data, but the specific location of the device is not [ref 2]. The area over which a cell provided service at the time of the call is likewise unknown, and must be estimated. This assessment is based on the information available, which may include the height of the mast, point direction (azimuth) of the cell used, local terrain and "clutter" (buildings, forests etc.), technology of the cells used and presence or absence of other cells. As part of this process, survey data may be used [ref 3]. To undertake Radio Frequency (RF) measurements, appropriate equipment must be obtained so that relevant network data (e.g. a Cell ID) can be recorded at a known location and time.

2.3 Analysis of a Call Data Record in the context of a case may be presented to a jury as a series of maps and tables, often with survey results. There is a difference between presentation, explanation, and interpretation of Telecommunications Data; If an explanation for data has been given, and there are other reasonable explanations that could have been given, this is by definition opinion evidence. Only Expert Witnesses can give opinion evidence in the court system of England and Wales, and then only in areas in which they are accepted as expert. There are competencies beyond purely technical skills that are required to safely interpret data. While survey readings result in factual information, the forensic inferences drawn from that data are subject to uncertainty and thus result in opinion [ref 1].

2.4 The ultimate aim of the analysis is to present transparent, logical, balanced and robust opinion. To provide such opinion, sound understanding of the uncertainties within all aspects of the examination is required; this paper is focussed on just one part of the wider forensic strategy – the use of survey data in an examination. It is emphasised that the discussion and analysis presented in this paper assumes that the survey data will be one of a number of analytical aspects assessing the wider question of whether the call data as a whole might be expected given the positions taken by prosecution and/ or defence. The dangers associated with splitting assessments into separate unrelated technical processes are outlined in a number of papers [ref 1, ref 2, ref 3]. To summarise, survey data should not be presented as a product in its own right in the absence of a wider evaluative framework and/ or by a practitioner who does not have expert knowledge of the artefacts considered (i.e. the CDRs).

2.5 Use of likelihood ratios are a broadly accepted approach to handling uncertainty within forensic opinion. This paper does not directly address this issue but does attempt to quantify some of the types of uncertainty that exist within survey data that might be one of the methods used in the forensic strategy. It is hoped that the work outlined herein will aid more targeted work in developing a robust inference model that may enable reliable generation of likelihood ratios, but it is accepted that the findings presented are the beginning (and not the end) of that process. The paper is therefore focussed on measuring uncertainties in survey data; Use of survey data (and technical conclusions about individual survey results) should not be equated with "cell site analysis" (and evaluative conclusions about whether the Call data might be expected given competing propositions). This paper does not address uncertainty – or how to address that uncertainty – in the wider process of Cell Site Analysis (e.g. CDRs).

2.6 There is no universally accepted solution of an optimal survey method and there are a variety of types of survey equipment available. The selection of equipment – and the manner in which that equipment is used - may therefore vary between practitioners. It is a requirement that the method (the equipment selected and the way in which it is applied) is validated prior to use evidentially. Failure to do so is in violation with the Forensic Science Regulator Codes of Practice [ref 4]. The validation should, amongst other matters, address the accuracy and precision of the method, which (along with reliability) in England and Wales is also a requirement of Criminal Practice Directions (CrimPD) [ref 5], Criminal Procedure Rules (CrimPR) [ref 6] and failure to adhere to the expected standards must be disclosed under the Criminal Procedure and Investigations Act (CPIA) [ref 7].

2.7 Assessments of the reliability of a method encompass more than just the equipment used. For example, a vendor's test might demonstrate with a high level of assurance that their survey tool operates exactly as a mobile phone does. The practitioner's purpose may be for a survey to predict which cells serve at a given location, and they intend to use the vendor's survey equipment to do so, confident of the data which that device provides from the vendors tests. The practitioner intends to conduct the assessment by using a single device for a 5-minute static survey and to report those cells selected as serving by the device. This method is now known to be deeply flawed (very prone to false exclusions) as an actual mobile phone only selects one cell as a server at a given time and tends to hang onto it, so is likely to only select a subset of legitimately serving cells in any given time period [ref 3]. This shortcoming would not be revealed by the vendor demonstrating that their device acts as a phone does; the issue concerns uncertainties in sampling that apply as much to a "real" mobile phone as to the survey device that has been developed to mimic that phone. In short, just because a survey tool acts like a mobile phone, it does not mean that it acts like another phone being used at the same place and time, or – more relevantly – like the suspect mobile phone did at the time it generated the CDRs considered. This issue must be accommodated in the wider assessment. Taking survey data at face value has caused issues in court in the past when such limitations have not been fully taken into account [ref 1]. The user requirement for a method is therefore not limited to the hardware used; the hardware is a core part - but not the entirety - of the wider method as defined by the practitioner. It is essential to understand how a device works and its limitations so that methods in which it is used can be designed accordingly, but it is also essential not to confuse the limitations of what a tool does with the limitations of how the data it generates are used within an examination.

2.7.1 A Vendors tests and assurances that their device accurately reports information therefore does not provide assurance that a given method in which those results are used is legitimate. The purpose of the method (i.e., what the technique is intended to achieve) is defined as an end-User Requirement [ref 8]. A common purpose is to highlight which cells may reasonably be expected to serve at a given location at the time of the survey. This survey-specific user requirement aids a wider requirement to assess whether the Call Data Records considered might be expected given the positions taken by the Prosecution and/ or Defence (evaluative mode) or to aid in providing speculative explanations for the data (investigative mode) [ref 1]. The findings presented in this paper are aimed at measuring the reliability of the survey methods under assessment to help achieve these aims, and to highlight limitations concerning conclusions that might be drawn from the survey data as part of wider analysis of the call data.

2.7.2 Within an End-User Requirement it is therefore important to separate the device used from the purpose to which the data generated by that device will be put. The user requirement will dictate the method; Validation of the method will include the tools employed, the risks and the output required. Separating the equipment used from the requirements of data generated by it is specified in the Forensic Science Regulator Codes and Validation Guidance [ref 8] [ref 9]. While vendors may perform technical testing concerning the legitimacy of information their equipment generates, it is for practitioners to perform their own (independent) validation of use of that equipment within a wider method to accomplish their specified forensic goal as defined in their end-User Requirement.

2.7.3 Within this paper there is:

- A technical discussion providing an outline of requirements and established methods for gathering survey data. Issues inherent to those methods and the manner in which they are reported is discussed. The core elements of this section are
  - The range of reasons why a survey might be undertaken
  - The differences in method that might be used to most effectively address the requirements
- The rules and ISO requirements surrounding how the requirements of the differing types of survey might be assessed and expressed within an analysis.
- A technical exercise attempting to quantify the reliability of the data produced by two fundamentally different approaches to generating survey data. The findings in this section are intended to be used by practitioners to inform their own methods and enable a more considered view on uncertainties within results they obtain. This aspect of the paper is primarily intended to help experts provide more informed opinion on the meaning of their survey results in the context of a case and highlight approaches to surveys that they may not have previously considered

3 Usage of survey data as part of a wider forensic strategy

3.1 To undertake RF measurements, appropriate equipment must be obtained so that relevant network data (e.g. a Cell ID) can be recorded at a known location and time. There is a variety of survey equipment available, including devices used by the telecommunications industry, equipment specifically targeted to the Forensic Science market and even apps for handsets. There is no universally accepted solution to performing surveys [ref 10]. The selection of equipment may therefore vary between practitioners, but it is a requirement that any method (the equipment selected and the way in which it is applied) is validated prior to use evidentially. Failure to do so is in violation of the Forensic Science Regulator Codes of Practice [ref 4]. The validation should, amongst other matters, address the accuracy and precision of the method, which is also a requirement of Criminal Practice and Direction (CrimPD) legislation.

3.2 Uncertainty within survey results is an expected part of this process and must be addressed as part of any wider method used; technical survey practices do not "stand alone" from the wider method in which the resulting data are used [ref 1]. In December 2017 there was a ruling in the Court of Appeal (R v Calland, Case No: 201705120/C1) which reviewed a decision to exclude Cell Site Analysis evidence presented at court. The Defence had objected to the prosecution relying on non-expert evidence to invite the jury to believe that a call made by a mobile phone in a particular location must be routed through a specific phone mast located nearby. They argued that the Prosecution had "unhelpfully conflated the location of a particular mast with the question of what safe inferences can be drawn about the location of a telephone using it"; these arguments were upheld. Presentation of maps and tables from potentially complex call and survey data (both known to contain uncertainties) as non-expert evidence, implying to a jury that this material supports an argument by Counsel without explicitly addressing any uncertainties (including accuracy and precision) is potentially unsafe and therefore does not form part of the methods assessed in this paper. Within this paper, it is expected that survey results will be presented as opinion and therefore as expert evidence by a practitioner who will be assessing the meaning of the Call Data in the light of the questions to be addressed. To do this, the practitioner must have wider competencies than using survey equipment, including (but not restricted to) expert knowledge of how CDR artefacts are generated.

3.3 There is an approach to forensic inference that is widely adopted in "traditional" forensic science, the Case Assessment and Interpretation (CAI) Model [ref 11] [ref 12] [ref 13] [ref 14] [ref 15]. This model is issued as a standard by the Association of Forensic Practitioners for opinion evidence [ref 16] and can be applied to Cell Site Analysis [ref 1] [ref 17]. It is not the purpose of this paper to fully explore use of the CAI model in Cell Site Analysis, but analysis of the survey data should, in the view of the authors, be one of the considerations in this wider process and not presented in isolation. Briefly, there are three levels of proposition:

- Source, which relates to whether a trace relates to a specific origin. In Cell Site Analysis this can equate to whether a given cell serves an area including a specific location. Source level propositions may be addressed via an assessment of a purely technical nature and may require little in the way of case circumstances to inform opinion. Thus, if case circumstances change, the results of source level propositions may not need to be reassessed
- Activity, which relates to the circumstances which led to a given finding. In Cellsite Analysis, such a proposition may be that a phone moved from the home address of a suspect to the scene. In some cases an activity level proposition directly addresses a specific allegation but in other cases the proposition is more indirect, for example addressing whether a specific individual was the user of an alleged phone. Case circumstances have a critical effect on formulating propositions and considering the probability of findings given those propositions; if the case circumstances change, a re-analysis may be required (in a way in which a source level examination may not)
- Offence, which relates to the guilt (or otherwise) of the suspect and should only be addressed by the jury

3.4 Whenever possible, experts should address two activity level propositions (usually the positions taken by prosecution and defence), prioritising those of greatest probative value. Opinion should be presented on whether the evidence (the Call Data Record, or CDR) would be more or less likely given each proposition. In the absence of a second proposition (for example a "no comment" defence), the expert is in a more difficult position and may adopt obvious alternatives, for example a home address (or other obviously relevant location) as well as those locations alleged to be frequented by the prosecution. In the absence of specific propositions an expert may advance speculative explanations for the data as a wider commentary ("investigative" rather than "evaluative" evidence). There are dangers when presenting investigative opinion that an expert may mislead, and they should distinguish between the two modes of thinking when presenting findings. The intent of the CAI model is to produce balanced, logical, robust and transparent scientific and technical opinion, thus avoiding the issues highlighted in R v Calland.

3.5 If an overly specific request has been made, so restricted that to answer it without additional activity may be misleading, a more balanced approach should be taken in the analysis. This principle directly applies to using Survey Data in isolation of a wider forensic strategy focussed on analysis of the Call Data Records. For example, hypothetically there is a request for a survey of a scene; it is alleged that the suspect (who accepts the phone) was at the location for a specific period, but the surveyor has not been asked to address this; it may be that no-one with wider expertise will be asked to formally assess the data.

- The analysis should be aimed at activity level (whether the data is expected given presence of the phone at the scene during the entire period it is alleged to be there) not source level (individual technical observations concerning specific cells, in isolation of the CDR and thus the wider intent of the examination).
- The request as stated may result in sifting for any data in keeping with the prosecution position. There may be data in conflict with the phone being at the location for the entire period alleged in the CDR, for example if end cells or other cells used close in time do not serve at the scene. Alternatively, a call event in a CDR may use a cell detected in the survey with a listed time during the offence, but this might be a GPRS event with time uncertainty and thus a misleading inference be made if considered by someone without expertise in matters concerning CDRs. The "data in conflict" assessment and understanding limitations in the CDR are clearly of relevance to the overall purpose of the examination, but this has not been specifically requested. Using the survey data to highlight only those call events to be expected given a specific proposition without deeper expert knowledge and reference to data in conflict with that proposition is misleading, and potentially unsafe, opinion evidence.
- Even in the absence of a declared defence position, obvious alternative propositions should be considered to comply with the "balance" requirement of the AFSP standard and FSR-C-118 ("Development of Evaluative Opinions") which explicitly applies to Cell Site Analysis (section 3.1.7). Within FSR-C-118, section 7.1.4 "…the expert needs to

develop their opinion based on consideration of both the positions of the prosecution and defence. Expressing a view as to the probability of the observations given one proposition without considering the probability of the observations given the other proposition is highly likely to be misleading and biased."

- Any alternative propositions (declared or adopted) should be explicitly declared. Within FSR-C-118, section 8.2.3 "On the basis of the case circumstances and any agreed key issue(s), the following shall be identified.
  a. The prosecution proposition(s).
  b. The defence proposition(s)."

4 Requirements for Surveys

4.1 Surveys may be performed for a number of reasons. For example, they may be used to form expectations of:

i) What cells might be in a CDR if a call were made from a specific location; A survey is conducted in isolation of CDRs in an attempt to establish which cells were detected serving at a location on the day of the survey. This might be thought of as a "presumptive test" to define expectations in any subsequent analysis as party of an "investigative" assessment

ii) Whether a CDR would be expected to be generated given a specific hypothesis. A survey is conducted to help inform an assessment of whether data might be expected given a specific proposition, almost always with reference to a known CDR. The calling data in its entirety should be considered against the hypothesis, and not progressed as a series of isolated judgements, thus forming part of a wider "evaluative" assessment.

iii) The general area over which the cell also served (a small cell is more discriminating as to where the phone may have been, and thus potentially of greater probative value, than a large cell). This is part of a wider assessment of the precision of a given finding (i.e. aid a jury in visualising whether the call data is distinctive or not)

4.2 The requirements are different between these cases – one is a prediction, one a test for an expected result given a proposition and the last an assessment of the precision of a given finding. The method by which the survey is conducted may therefore differ according to the question to be addressed. The question to be addressed by the survey may therefore have a critical effect on the selection of survey method (both the equipment selected and the approach taken). Reliably highlighting cells expected to serve at a location may require a different approach to a confirmation (or otherwise) that a known cell serves at a location. Likewise, a survey in a rural location may require a different approach to a survey in an urban location. For example, relative height between survey equipment and the location of interest is one element that should be considered prior to any survey being undertaken (i.e. in the planning phase). Likewise, locations with expected unusual characteristics, such as flats within high tower blocks should also be identified and dealt with appropriately, as survey results (however competently undertaken) at ground level may have little bearing on the cells serving on higher floors.

4.3 A survey may be conducted to highlight those cells observed or expected to serve at a location. For example, this may be to:

- Preservation around areas of interest. A 'blind' survey at a location may be conducted to capture data soon after the incident. If further measurements are required to, for example, establish the most likely service area of a queried cell, these measurements may be flawed if there have been local changes to the network in the intervening period. Overview data from the initial survey can be used to assess (and validate, if there is agreement) later, more detailed, data
- Provide an overview of those Cells which provide service in the immediate vicinity of a specified location to advise future queries in the investigation (for example to assess if the Cells observed occur in specific Call Data Records at relevant times)
- Identify those cells for which a 'cell dump' may be requested to highlight devices which may have been at the location in a relevant period

There is clearly a necessity to ensure any method used is likely to capture all legitimately serving cells and be robust enough to exclude those cells that do not provide service; validation exercises must therefore include an assessment of 'false negatives' (i.e. exclusion of legitimate cells) and possible 'false positives'. This method may be used as part of a wider process informing investigative opinion, for example reviewing CDRs to cross reference when cells detected as serving at locations of interest were used. While this may enable a quick review of data that may provide some insight in an investigation, great care should be exercised when using such results; just because a cell was used that was detected serving at a location does not necessarily mean that it was reasonable that the phone was at that location at the time of its use. For example if other cells were used close in time that do *not* serve the location of interest, the phone would be expected to be in an area of overlap of those cells, which may not include the location at which it was detected serving (i.e. the phone was elsewhere in the service area of the cell that was detected serving at the location of interest). There is also a danger that if a cell was detected serving at one location, but was falsely excluded from another (a 'false negative') and therefore not highlighted as serving there, unsafe conclusions may be drawn concerning the probative value of the finding. A case example of a failure in such a method has been presented [ref 1].

4.4 A survey may be directed at addressing whether the call data would be expected given a specific proposition by carrying out limited survey measurements to demonstrate whether the Cell of interest covers a specific area. This enables practical assessment of hypotheses and can demonstrate if:

i) a specific location of interest is served by a queried Cell
ii) a sequence of calls through different masts is expected given a specific proposition

4.5 If a cell is observed to provide service at the location of interest, additional work may not be necessary (although additional assessment of the service area may aid in highlighting the precision of the finding). If a cell is not observed, with the implication that the call data is in conflict with the proposition the device were at the location, there is clearly a necessity for additional activity beyond such a basic approach e.g. visiting the mast location to assess whether the cell of interest is on air and conducting a more intensive location survey. Another form of scenario testing could include an assessment of whether a particular address has good/ poor/ no service from a network.

4.6 A survey may be undertaken to aid in assessment of the service area of a given cell. Cell Mapping is a different approach to a location survey. In this case, rather than surveying a known location and assessing those cells likely to serve there, a known cell is the starting point and activity is aimed at estimating the area over which it serves. Mapping a cell gives a context to a given call (i.e. it illustrates the size of a cell). Cell size can vary between a hundred metres or so and tens of kilometres. This can provide a useful illustration of how discriminating usage of a specific cell may be and can be of probative value depending on the cell size in relation to the case circumstances; cell mapping is one form of assessing the precision of the finding as required in CrimPD. Where a number of cells are used in quick succession, or are commonly used over a period of time, assessments of the areas of overlap between the cells can potentially offer greater discrimination of the expected area in which the device was used.

5 Type of Survey equipment

5.1 To undertake RF measurements, appropriate equipment must be obtained so that relevant network data (e.g. a Cell ID) can be recorded at a known location and time. There is a variety of types of survey equipment available.

5.2 A phone emulator is a mobile station (i.e. a radio with a SIM card in it complying with the appropriate standard – e.g. GSM) which shows details of cell selection and reselection and (usually) records this and provides a GPS co-ordinate for the reading. The obvious advantage of this type of survey device is that as it is a mobile phone, there is no concern that it doesn't act like a mobile phone. The data is (barring any failures, such as loss of data or GPS lag) likely to be valid under most circumstances. A disadvantage of using this type of survey device is that as it is a mobile phone, it is subject to the variations imposed upon it by the network to which it is attached that may be situation specific. Just because the survey device and the suspect device both operate to the same technical standard does not mean they will automatically select the same cell at the same location, even if they are there at the same time. For example, a Call Data Record may be initiated because of specific user activity such as a smart phone accessing data services. The band used (and thus the Cell ID listed in the records) will be dependent on a number of factors including (but not restricted to) the type of service being used, the context of that use (i.e. which cell the device is currently using, itself influenced by the physical location and previous usage of the device) and the services available to the user (those available in their contract). Elements of these variables are unknown to the surveyor, and thus these variations are impossible to fully replicate. This form of equipment may be designed for the forensic market (and not look like a phone at all), providing just that information that is required to assess cell selection and reselection. An example of this type of device would be the CSurv range by 3G Forensics. Alternatively, it may be designed for the telecommunications sector and thus provide wider functionality. This type of equipment may be a specially adapted mobile phone handset. Examples of this type of device would be Nemo Handy by Anite or the TEMS range of engineering handsets. It may also be a bespoke application designed to run on a smartphone or tablet, which may be produced within an organisation and not necessarily be available commercially

5.3 A scanner is a radio receiver that does not authenticate with a network, instead it shows details of carriers detected within a set frequency range. The software will not necessarily emulate the algorithms that a mobile phone would use for cell selection. An advantage of this type of equipment is that because it isn't locked to a given network it can scan all of them, making it a cheap survey solution for all network surveys on the technologies supported by the tool. Another feature is that as it doesn't follow normal cell selection and reselection protocols of a given system it can therefore show all detected cells and not be directed to select from a subset of them. This can provide added assurance when concluding that a cell is not a legitimate server at a given location, or be used to assess what cells are based at a given mast. An obvious disadvantage of this type of equipment is that as it isn't acting in the manner of a mobile phone, assessing which cells legitimately serve at a given location may be more complex and prone to error; the cell with the strongest signal will not always be the one that might be selected by a mobile device for service at a given location; indeed most locations will have more than one legitimately serving cell (known as 'non-dominance'), and interpretation of scanner data may be very complex under such circumstances (i.e. it cannot be said that all of the cells detected by a scanner would necessarily provide service).

5.4 Software Controlled Radio (SCR) is a radio receiver that does not authenticate with a network, and shows details of carriers detected within a set frequency range, like a scanner. Where it differs from a scanner is that it includes software which attempts to emulate the algorithms that a mobile phone would use for cell selection. An advantage of this type of equipment is that because it isn't locked to a given network it can scan all of them. It is also able to automatically assess which cell at a given time would potentially have been selected as a serving cell on each network, technology and band simultaneously. It therefore has the advantage of a:

- Scanner in monitoring all network, technology and bands (without the disadvantage of understanding how to use that data to assess the serving cell)
- Phone emulator in highlighting a serving cell, without the disadvantage of partial band or technology monitoring

There may be additional functionality within an SCR that is of use in cell Site Analysis, for example automatic estimations of the locations of cellsites on which a detected cell is based.

6 Survey methods – General Principles

6.1 The way in which survey equipment is applied is just as important as the type of survey equipment used. As with survey equipment, there is no universally accepted way of conducting a survey that applies to all scenarios and there are many options available, each with its own advantages and limitations. It is a general expectation that there will usually be more than one cell on a given network, technology and carrier providing service at a location [ref 1], and the context in which a phone is used may affect the cell selected. The method used to conduct a survey may therefore differ according to case circumstance, and that selection should be influenced on the known limitations of the different methods available. The context in which the call event takes place will also influence the cell used, and this context may be apparent in the CDR. For example, Circuit Switched calls may be preferentially handled by different carriers than data events; if the state of the target device is not known (and this would normally -if not always- be the case) then emulating exactly what the suspect device was doing will not be possible.

6.2A survey can add greater clarity as to which cells were detected as on air, and whether they may (or may not) have served at a location, but obviously these measurements will almost inevitably have taken place at a different time than the calls in the CDR being considered. Not only may there have been network changes in the area between the time of the calls and the time of the survey but there will be local variability in a survey (e.g. time dependent fading) that cannot be perfectly replicated between the suspect device and the survey. The presence of these uncertainties does not mean that surveys mean nothing, but they do mean that survey results should be treated with caution and, whenever possible, strategies to accommodate those uncertainties employed.

6.3If a survey method always returns every legitimately serving cell at a location with no false inclusions, this would be a perfect method. If it doesn't, then by definition there is uncertainty in any results considered. To the knowledge of the authors, there are no perfect survey methods. For example, static survey methods (where survey measurements are gathered from a single point) have been used in court and yet are demonstrated to be particularly susceptible to false negatives [ref 3]. If such a method is applied where the entirety of the wider interpretive process is to cross reference those survey results with cells occurring in the CDRs this may at best result in an incomplete understanding of the matters considered, and at worst potentially misleading the jury [ref 1]. The main dangers are:

- Falsely excluding legitimately serving cells. This is a real possibility for most, if not all, methods.
- Falsely including cells that could not provide service.
    - Assessment criteria of opinion of possible service may be inappropriate. For example, if a scanner were used as a survey tool it does not directly indicate service of a cell; if a practitioner were to define service as "anywhere the signal was detected at a strength high enough to make a call" this would not take into account real-world considerations of an actual mobile phone and be a gross overestimate of the true service area of a given cell [ref 18]

   - Readings when initially switching on for some devices can include checks for the last cell used by that the device, potentially falsely including a cell as detected as serving at a location

6.4 A mobile device will only use a single cell at a given time, and will tend to "hold on" to this cell. This is explored in some detail on the GSM network [ref 3] in which of the 6 cells detected as serving by at least one device, no device detected more than two of them using a static method, even with a sampling period of an hour. These concerns amplify on non-GSM networks. For example, at the time of writing, in the UK the "EE" network has one band on GSM (2G) network, but for the 3G network has four different carriers, meaning that the potential variation within the survey results may be four times as great for 3G results as 2G. On LTE (4G) there are at least thirteen carriers. If there were 6 cells serving at a location on each given technology and these were "stacked" (additional cells transmitted from the same aerial) across all available carriers, there may be 100 or more different serving cells. Clearly any survey method needs to take such technical concerns into account from the outset. On top of this uncertainty, networks may change over time as sites are decommissioned, new sites implemented or service is optimised via smaller changes (for example physical changes such as azimuth down-tilt, frequency retuning, cell renumbering etc.). It is a requirement of the expert to assess and express uncertainties in their opinion [ref 5]

6.5 A scanner or software controlled radio will, in general terms, operate consistently between deployments. A phone emulator can be used in a variety of ways to attempt to address some the concerns outlined above.

6.6 When a mobile device is on, but not transferring data to/from a network, it is in 'idle' mode. While in idle mode, the device 'listens' to the network and selects which cell it calculates as the most appropriate on which to initiate a call. The 'start cell' in a call data record is expected to be the cell which the mobile device has selected while in idle mode. Survey equipment operating in this mode should accurately reflect what a mobile device is doing most of the time, including at the point of selecting a given cell. This is an obvious advantage when assessing those cells that are likely to be selected at a given location. A disadvantage is when 'unusual' cells are in a Call Data Record (such as the example given in the 'phone emulator section'). In such cases it may be unlikely that survey equipment cell selection and reselection will behave the same, and so the cell of interest may not be detected whether or not it provides coverage.

6.7 When a device is in active use (in call or, for the purposes of this document, transferring data which in telecommunication terminology may be referred to in different terms) it is in 'dedicated' or 'connected' mode. This means that it is actively in two way communication with the network, and behaves differently to when it is in idle mode.

- This can be an advantage when, for example, assessing whether there is service of a network at a location. While a successful call obviously demonstrates service, an inability to make a call does not necessarily indicate that such a call would not have been possible, as the survey device may be of lower sensitivity than the target device

- For GSM, dedicated mode may be of use in some circumstances (e.g. demonstration of service, assessing end cells or anomalous 1800MHz start cells for O2 and Vodafone GSM network, which would not normally be used to initiate a call and would not be normally selected by a handset in idle mode).
- When a device is in call, the decision of which cell is to be used next is influenced by the network and may be affected by other factors of which the handset may be unaware, such as the amount of traffic on local cells or the quality of the uplink. While all cells used in a call will not necessarily be in the data record, the end cell will often be. Connected mode can be used to assess these end cells but care needs to be taken as it can never be known that exactly the same network circumstances are in place at the time of the survey.
- Connected mode reduces the sampling rate (this may be mitigated by using multiple units) and thus the data points in a survey as well as increasing uncertainty in the exact location of a specific data point (if mobile) and less opportunity to select a given cell as serving if it provides service at that location.
- Connected mode results are not produced by a resultant CDR but are equipment generated (before there is chance for handover on some systems). They are therefore no more or less relevant than idle mode measurements under most circumstances.
- Connected mode operation is not available for scanners or SCR as they do not authenticate on a network

6.8 Mobile Phone networks may use a variety of frequency bands, and each band may be used in different ways by a device (for example one frequency primarily for voice calls, another for data etc.). Devices may be able to monitor all relevant frequencies but default to just one, and thus miss relevant data. Some networks may be configured so that some frequencies are unlikely to be selected to initiate a call, and if the device which is the subject of the examination has used a specific cell on such a band, the circumstances may be nearly impossible to replicate. Locking survey equipment to a specific frequency band provides opportunities to ensure that all relevant data is captured in a survey.

- Disadvantages of locking may include; Network configurations may change, the full range of carriers may be unknown to the practitioner; If a single survey is desired, many more pieces of equipment will be required if they are to be simultaneously deployed, with resultant complexities in data handling; if multiple surveys are used due to lack of availability of equipment, this can be time consuming (not so much the time taken to adjust settings on the device the extra time required to repeat the survey; spurious (incorrect) data in areas where the frequency of interest does not provide coverage (some survey devices are known to roam to other networks without recording this, or continue to record the last monitored cell until a new cell is observed, resulting in "dragging" or suggesting a cell serves a wider area than is true);
- This consideration does not apply to scanners or SCR

6.9 In idle mode, a mobile device will select a cell and often hold onto that; this selection is usually primarily influenced by the relative signal strengths of the cells considered and the period over which there has been a significant difference. The cells to be monitored for handover will be dictated by the cell the device has currently selected; these may differ between cells in a given area and hence it is possible that some legitimately serving cells may not even be monitored if the cell selected as best server does not include them in the list. A device can only report one cell as 'Best Server' at a time (but may provide some additional relevant data, e.g. an "active set" in UMTS). If a cell of interest is detected using a single device at the location of interest, then additional activity will not add to the conclusion drawn (i.e. the cell is known to serve the location, further surveys will not change this). If, however, the cell is not detected, or selected as 'Best Server' using a single unit, the conclusion that it does not serve may be unsafe without additional activity. Every additional unit deployed will provide a better chance that all legitimately serving cells to be detected. This consideration does not apply to scanners or SCR, as they do not "hang on" to cells in the same way as engineering handsets.

6.10 There are times when movement will be required within a survey, for example when testing a hypothesis which involves movement. When there is a single location highlighted, movement can also be useful as the location may be defined as the footprint of a property, for example, which is not a single point:

- If the location is a building, the closest points to the north, south, east and west of the location can provide a better and more informed view of the range of cells that provide service there
- Large scale movement (many hundreds of metres) to and from the location from many directions can also force cell reselection, thus providing new survey information at the location independent of that which preceded it. Spatial hysteresis (especially at location area boundaries) can be accommodated within the survey
- Large scale movement can also provide a more informed view of the local RF environment and may provide indications of, for example, cell boundaries if over a wide enough area
- There is an added complication in processing data from mobile surveys as the data will be from areas that may be some distance from the location of interest which will require some form of post processing to remove less relevant data. Expectations of the uncertainties in the measurement of cell boundaries is therefore necessary when assessing this type of data.

6.11 Static surveys have the advantage of enabling quicker and easier analysis of data (i.e. a file of readings can be produced from a known single location close to or at a location) and may therefore be used in their entirety. There is also an advantage in static surveys when, for example, there is a timing offset for a cell (time hysteresis). However, there are also known failings with a tendency to miss legitimately serving cells [ref 3]. The location which is chosen for a static sample may be critical, there can be great variations over small distances; this is clearly an issue if a static sample is used to represent service to an area (e.g. a house), as there may be a variation of cells serving at the back or front (and also potentially vary with height). Given the known issues with equipment only selecting a subset of legitimately serving cells, if the survey data is to be used to potentially exclude cells, an assessment and understanding of 'false negatives' must have been undertaken.

6.12 Some carriers may only be accessed according to the services for which a given phone is subscribed, or for certain activities (e.g. GPRS). Furthermore, network settings for specific cells may disadvantage those cells for a period of time (for example to discourage moving traffic from selecting them). This means that detecting all legitimately serving cells on all carriers is extremely difficult in a survey, survey methods are demonstrably imperfect at doing so and it is reasonable that many legitimately serving cells may not be detected.

6.13 From the comments above, a practitioner might feel that a "perfect" survey for assessing those cells that serve a location may be highlighted as a combination of all methods, i.e.:

- Parallel use of Multiple pieces of mobile-emulator equipment
- Multiple modes of use (idle and dedicated)
- Big movement (many hundreds of metres) to and from the location from many directions
- A period of static survey at a location, including a dedicated mode call held for a longer period of time
- If a cell of interest is not detected, a visit to the mast may be pertinent to ensure that the cell was on air at the time of the survey
- Use of Software Controlled Radio (which negates the need for a scanner) to ensure that the full range of carriers are monitored and legitimately serving cells are less likely to be falsely excluded

6.14 Even this time consuming and equipment heavy method would not be perfect. The survey can only reflect the network as it is at the time of the survey; if a cell of interest is off air, no amount of time and equipment will detect it and this may lead the practitioner to unsafe conclusions if not considered. If the requirement is to assess a specific cell, and this cell is initially selected as serving, any additional time and effort is wasted after that point, so there may be an issue concerning efficiency. Static surveys could not encompass all of a given location (which will not be a single point, but a defined area such as a property). The survey units themselves are constrained, e.g. by the height of the antenna and being used in a confined geographic area (e.g. a road system). Additionally, the criteria for whether a cell serves or not may not be immediately obvious or agreed between experts (for example, a cell detected serving 70 metres away but no closer may be interpreted by some examiners as within the uncertainty of the method, but disputed by others)

6.15 No 'ideal' survey method is therefore recommended in this paper even for a single type of survey. The limitations of the method used, in conjunction to the question to which they are applied, must be assessed and disclosed. Methods with known issues in answering specific types of questions must be avoided or those issues explicitly discussed as part of any resultant analytical report. Validation of any method used is, of course, mandatory [ref 8].

7 Assessing uncertainty within survey data as part of providing opinion in Cell Site Analysis

7.1 Defining the purpose for which the survey will be used is essential. There is a significant difference in expectation of a method to consistently give a perfect representation of every cell which is expected to:

- Highlight every legitimately serving cell at a location, and not include any that could not be selected by a phone when there. In this case, any level of false negative error rate may be deemed unacceptable; this is an extremely high bar to achieve in any method, and may not be possible
- Provide information that will help inform opinion when considering the call data in parallel with other sources of information

7.2 The specification of the method therefore needs to be highlighted so that the validation requirements can be defined. For example, the survey tool may need to:

- Detect and record a serving Cell ID
- Record a location (potentially also defining the co-ordinate system to be used)
- Provide other data, for example received signal strength, frequency, neighbour cell data. Some of the requirement may be to report absolute measurements (for example detected signal strength)

7.3 Risks must be defined, and the impact to the evidence should those risks be realised identified. A survey method may potentially provide:

- False negatives – failure to detect a legitimately serving cell may appear to exclude use of it from a location at which it was actually present
- False positives (provide a result which indicates a phone may have been at a location even though it could not have actually been there)

7.4 The issues surrounding validation of survey methods include the source data (i.e. the air interface radio environment) being outside the control of the validation exercise. This is unusual for most validation areas, as the easiest way to assess the accuracy and precision of a method is to test it on a defined data set where explicit comparison against a known, completely true, answer can be achieved. In the absence of an ideal and entirely predictable mobile phone network controlled by the person performing the validation, the complete 'true' answer will be unknown. Thus, if there are a range of possible answers, these may be difficult or impossible to accurately define, although it may be possible to define a subset of correct answers. There is therefore a limitation to the validation from the outset:

- The complete range of 'true' answers is unlikely to be definable. The true accuracy and precision of the equipment cannot be easily tested
- The assessment of the validity of the tool will be affected by the validity of the manner in which it is used which is likely to require separate validation

7.5 The validation strategy may include more than one approach and becomes more robust if combinations of them are adopted. If the output is to be interpreted in any manner, this interpretation needs to be tested. Possible approaches to validation could include tests as to whether the tool is consistent with its own output at a different time or other identical devices at the same time can be performed. Ideally, two or more devices would be available for simultaneous deployment enabling direct comparison of their output. This can provide a measure of the precision (variability or expected range of results) of the method. In addition / alternatively, if other tools have already been through a full validation, and are accepted as legitimate devices for comparison, they can be simultaneously deployed and the outputs compared. The method of deployment should also be varied so as to 'stress test' the tool (i.e. expose it to a variety of conditions and therefore increase the likelihood of detecting shortcomings). This approach has a number of virtues

- The 'true' answer does not need to be known as it is a straightforward comparison of output from different tools that is being performed.
- While the 'accuracy' cannot be assessed (as the true answer is unknown), the differences in output can be assessed and hence a comparison of the uncertainty of measurements can be made. In this example, this is related to the 'precision' of the device.

7.6 Calls may be made by an individual and the call data records requested from the relevant telecom service provider. The person using the phone records where they were at the time of the call. This can provide a measure of the accuracy (whether results from the method include the correct answer) of the method. If the trial also forms part of a competency assessment, the location should not be shared with the person performing the analysis. This approach has a number of virtues:

- The approach tests the equipment against the same situation it is likely to be deployed in live casework.
- At least one 'true' answer is known, i.e. if the cell that was used at the time of the call is detected using the equipment under test as serving where the call took place this is clearly a valid result.

7.7 Only one cell is provided in the call data for a specific call event, even if many cells are capable of providing service at a given location [ref 3]. Selection of any of these other, legitimate, additional cells by the test equipment is not therefore an incorrect answer (i.e. they do not indicate "false positives"), but as these other 'correct' answers cannot be specified in advance it may not be clear if the equipment is actually functioning as hoped. If a legitimately serving cell (i.e. that in the Call Data Records) is not detected at the location where it is known to have served, additional assessment may therefore be required. For example, the approach adopted for deployment of the equipment may be at fault (some methods are known to be more prone to false exclusions than others) or there may be some other reason (e.g. the cell in question may have been off air at the time of the test survey). As such, even blind trials cannot be definitive and should not be used in isolation from other validation approaches. Ultimately, this approach is unlikely to highlight false positives (including an invalid cell in the test output) but may spot false negatives (artificially excluding a legitimate cell).

7.8 Tests as to whether the tool operates as expected when in areas where there are network configurations known to cause potential issues in survey results. For example:

- Edge of service, in particular where some bands provide service and others do not
- LAC boundaries, where hysteresis settings may affect cell selection
- Use of bulk data to assess general behaviours of survey equipment, and specifically look for data that may indicate limitations (e.g. assessing which carriers are monitored within the data)

7.9 Now that a strategy has been defined, a detailed plan involving combinations of the options above can be drafted. This may include detailed planning and documentation of:

- Blind trials at known locations, testing elements of the accuracy (i.e. whether a 'true' answer generated by a 'real' phone is reported) of the method. This also tests both the equipment and the operator
- Consistency trials, testing the precision of the method (i.e. the range of results returned and whether that range is replicable). This may include a comparison of output in different environments (e.g. at a location, along a route, in a rural area, in an urban area) for
    - Multiple test devices deployed simultaneously
    - The same device deployed in the same environment at different times
- Stress testing, ensuring that legitimate results are returned even in situations likely to cause issues

7.10 Expected test results for a 'valid' method can be defined (e.g. that a known serving cell is detected in a blind trial). An assessment of the test results against the expected "pass" criteria is made and documented. This should include an outline of the uncertainty in reporting serving cell results. For each of the deployment methods, the variation of results should be defined. For example, if analysing a blind trial and the location survey results the accuracy and precision could be assessed

- Was the cell that was known to serve the location within the results specified by the tool? If not, is there a reasonable explanation as to why not (e.g. cell off air)
- If more than one cell was detected were the same cells also detected if the survey was repeated? Were the same cells detected by other units simultaneously deployed? Were the same cells detected by other, independent, systems?

7.11 Within Cell Site Analysis, the complete 'true' answer is unknown (i.e. the full list of serving cells is unknown, only those cells selected in the blind trials are known), so a full and quantitative assessment of accuracy and precision is not reasonable, but this does not mean that they cannot be assessed at all.

7.12 Reporting measurements in standard units may be achieved by comparison of measurements against a known, externally assured, standard signal, preferably in a radio isolated environment (e.g. a Faraday Cage). The expected received power at a specific distance from the signal generator can be calculated using established methods, and the output of the method compared to the known true value. Comparisons of the measured and true values can then be made to establish the closeness of each result (and the mean of all results) to the known correct value (the accuracy) and the range of values (the precision). Once this has been established, the effect of the actual value measured on the question to be addressed (e.g. how the absolute signal strength affects selection of the serving cell) would also need to be assessed for it to have any meaning. This example is based on reporting standard Radio Frequency power measurements (e.g. dBm) but could just as easily be audio frequencies or any other method which outputs results in standard units (e.g. Hz, nm etc.). It is difficult to see how any method reporting measurements in standard units could be validated without reference to an externally assured standard unit and, ultimately, such information is of limited use. A cell is either capable of supporting the relevant call event from a location or not, the absolute value is of little relevance and may vary between devices according to their sensitivity (i.e. the survey device may have different antenna characteristics than the suspect device).

7.13 Standard Operating Procedures should be drafted to cover both use of the device and also how the results of the method will be incorporated into the wider analysis. The method is more than just the tool, or the competency of the person operating the tool and includes how the information derived from the method is used. Just because a method is assessed as valid for reporting legitimate cell information, this does not mean that anyone using it is automatically competent to interpret the output or give opinion on the meaning of the results. Competence for these activities must be explicitly assessed in addition to the tool itself.

8 Using Survey data

8.1 An assessment of call data against the stated propositions will consist of a series of individual technical assessments, each of which should then be combined to enable an overall opinion on whether the data (in its entirety) might be expected given the propositions considered [ref 1]. Thus an overall opinion may be formed by combination of a number of technical observations, all of which contain uncertainty, that ultimately result in a technical opinion addressing Source Level propositions. A number of source level propositions might themselves form part of a wider activity level assessment, for example whether the data might be expected given movement of a device to and from locations of interest.

8.2 An assessment of whether it is likely that the device was at the location is quite specifically <u>not</u> being addressed. Assessing whether the call data would be expected given the proposition is <u>not</u> the same as assessing whether the proposition would be expected given the call data. To make such an assessment would be a "transposed conditional" and is a failure of forensic inference [ref 1]. The matters in which the survey data may inform opinion include:

- Did the Cell used in the CDR serve an area including that location at the time of the survey?
- How sure of that can we be? If a given cell is <u>*not*</u> detected, does that mean it couldn't serve? Should this be raised? (linked to accuracy).
- How discriminating are the findings? (linked to precision)

8.3 The opinion given may be heavily influenced by the survey data, but care should be taken to fully equate a survey result with a final opinion of service; there will be other factors that should be considered to make a safe inference which are outlined above, including other information such as antenna point direction, height, local matters such as terrain, the wider call data and known limitations to the survey method used.

8.4 There are therefore dangers in viewing survey data as being able to reliably produce match/ non-match outcomes. Understanding, measuring and expressing the uncertainty of the observation can be problematic. Given the undisputable presence of uncertainty within survey measurements, survey data must therefore be used to inform, not define, opinion on where a given cell serves and be used in conjunction with other information. The manner by which overall opinion might be expressed when assessing whether the call data as a whole might be expected given specific propositions is covered by the CAI model; this overall opinion will rest on a series of observations concerning each call event. These observations usually take the form of technical sub-opinions concerning cell service, each of which is subject to uncertainty. While the strength of opinion for each observation may be on a continuous scale there may, however, be a limited number of overall conclusions. For example, technical opinion concerning service of a specific cell at a location may often fall into one of five broad categories:

[One] "I would expect the cell to serve an area including the location, and I have demonstrable information that suggests it did"

- The cell was observed to serve at the location at the time of the survey
- The cellsite is close (a few hundred metres or less), on azimuth, with no terrain or clutter and with Line of Sight. In this circumstance, an expert may conclude that it really doesn't matter what any survey data might or might not show, it's unreasonable to suggest that the cell considered wouldn't be among those cells serving at the location

[Two] "It is reasonable that the cell served an area including the location"

- Another way of expressing this might be via a double negative – "it is unreasonable to conclude that that the cell couldn't serve an area including the location". In this case, the expert cannot directly demonstrate service (for example due to possible "false negative" in a survey) but is of the belief it serves due to other, potentially compelling, data
- For example, if a cell overlaid with the cell of interest was detected serving at an urban or suburban location (but not the cell of interest itself). There may be exceptions to this type of technical conclusion (e.g. cells at the edge of service in rural areas where a higher frequency channel may not extend as far as a lower frequency channel) and therefore a range of opinions may exist between experts from the same source data

[Three] "I do not know if the cell did, or did not, serve an area including the location"

- The expert does not feel confident enough to draw any firm conclusion.
- For example, if the cell was not detected as serving, but there were neighbour measurements of strengths sufficiently close to that of the serving cell to leave an expert unsure of whether it might or might not be selected at the location
- If there is known to have been network changes in the area, then clearly this may limit the value of survey results

[Four] "I would not expect the cell to serve an area including the location, but cannot fully exclude the possibility it may have"

- For example, other cells were detected serving at the location and service of the cell of interest was detected close (but not too close, in the view of the expert), there was no terrain obstruction etc.

[Five] "It is not reasonable that the cell served an area including the location"

- This is potentially a deductive inference (so a stronger opinion than any of the previous conclusions). The validity of the conclusion will be based on the validity of the assumptions and there is no uncertainty.
- For example, a non-extended range GSM cell cannot provide service greater than approximately 35km from the mast. If the expert has correctly normalised the call data (so is addressing a cell used by the target device, and not "other party" cellsite information that may also be in the data) and the cell data is correct, it would be a deductive inference that the cells could not serve at any location greater than 35km from it. There may still be uncertainty concerning the time of use of the cell (for example, there are known uncertainties in the apparent times of use of cells in GPRS records)
- There may be less extreme occasions when this conclusion is drawn, for example if a cell other than the cell of interest but with potential for co-channel interference (e.g. on the same ARFCN or PSC and carrier) serves at the location

8.5 If there is evidence that an expert believes suggests there may have been network changes in the area under consideration, these should also be communicated if they have any bearing on the matters under consideration

8.6 It is emphasised that the discussion above is for the individual technical observations that collectively influence opinion as to whether the Call Data as a whole might be expected given the propositions considered. There would also be other factors that would need consideration (for example uncertainties in the generation of each call record). Once all have been considered, there is a verbal scale used within the Case Assessment and Interpretation (CAI) model linked to a likelihood Ratio calculation (LR). For example, "moderate support" for one proposition over another is associated with a LR of 10-100. At the time of writing the authors are not aware of a method for reliably generating calibrated likelihood ratios in cellsite analysis and thus are wary of directly mapping individual technical findings onto the verbal scale used by other more established fields at this time.

This does not mean that such a method cannot be developed for cell site analysis; to do so, quantification of the uncertainties in the methods used will be required and this paper presents an initial attempt at this to be built upon. It is quite routine in cell site analysis for an assessment to be made of the call data in the absence of a pair of propositions, either because the data is in a period in which there are no allegations, or because there is no stated alternative position [ref 1]. Thus experts are often limited to making comment on whether the data might be expected given only one proposition; this inability (rather than unpreparedness) to provide a fully evaluative opinion should of course be declared, but the practitioner should also provide some indication as to how discriminating or distinctive their technical findings might be. The difficulty of establishing a robust evaluative model is not unique to cell site analysis, digital evidence fundamentally changes with time as the technology that produces the artefacts considered progresses in a way that, for example, properties measured in glass evidence do not. This speed of change results in a requirement for interim solutions for inference, as discussed by Casey [ref 19] which proposes a C-Scale in the absence of the ability to generate a reliable likelihood ratio. In any event, it is clear that technical findings on individual cell service should not be used out of the context of the call data considered, and thus the broad categories above are proposed as stages within an analysis itself rather than a final way in which overall findings are expressed.

8.7 Cells serve areas, and by definition a large area will be less discriminating in defining the range of possible locations of a device may have been than a small area would be. There will be a general expectation of the sizes of "normal" cells which should be presented in any report, but it may be worth flagging particularly small or particularly large cells if the calls were in periods of specific interest. If findings are presented as "investigative mode", or in the absence of a second proposition, it is obviously relevant to highlight whether the technical findings are distinctive or not.

- Small service areas (e.g. pico cells)
    - Cells with expected ranges of a few hundred metres would be in this category
    - These cells may often have a low antenna height in a dense urban environment constrained by local terrain, clutter (e.g. surrounding terrain or buildings taller than the mast and likely to constrain signals from it) and presence of other local cells
    - Often survey results can be compelling evidence to support opinion on this level of precision. The cells with the greatest discrimination are also likely to be the cells which are quickest to fully survey
- Large service areas (e.g. large rural masts)
    - Cells with expected ranges of many kilometres would be in this category
    - These cells may often have a high antenna height (often 30 metres or more) on higher terrain in a rural environment, with much lower cellsite density

8.8 The expert should, if possible, be primarily addressing activity level propositions, and therefore needs to be able to safely relate source level conclusions to the activity level propositions that are their prime concern. A report should not merely be a series of source level conclusions, implying meaning on a wider activity level proposition, expecting jurors to sort out their meaning in the context of the wider questions at hand. For example if there was a source level opinion presented on whether a cell served an area including a location of interest and the source level conclusion was that "I would not expect the cell to serve an area including the location, but cannot fully exclude the possibility it may have" this may not map directly across to an activity level opinion as:

- If a single call were considered in the context of other data that would be expected given the proposition (that the suspect was the user of the phone) concern may be raised about the uncertainty in this single event, but the overall activity level conclusion might be that the data would be expected given the proposition
- If there were many calls only on this cell over an extended period, a different conclusion may be drawn on whether the data would be expected given the proposition the suspect was at the location

8.9 The same source level observation may therefore result in very different activity level conclusions.

8.10 A source level proposition may sometimes directly correlate with an activity level proposition. For example [ref 1] details a case in which an analysis essentially condensed to a single source level assessment: "The prosecution allege that the suspect was at the scene, the defence allege he was at home throughout the period of the offence. Cell A was the only cell used by the device during the period of the offence". The technical question at hand can thus be addressed at source level as "Does Cell A serve an area including the scene and/ or the alibi location?". As noted in that paper, there are a number of outcomes such an assessment may result in, that may aid a jury in coming to a conclusion:

i) Probative value: Prosecution. The cell serves the scene but does not serve the alibi location
ii) Probative value: Defence. The cell serves the alibi location but does not serve the scene
iii) No Probative value: The cell serves both the scene and the alibi location (and cell site analysis is of no use for this question at hand)
iv) Investigative value: The cell serves neither the scene nor the alibi location (and another explanation for the data may be required)

8.11 If a "false negative" source assessment excludes service at one location but not the other, this can obviously end in a position where a false impression may be given to the jury concerning the value of the evidence. This could potentially result in a false conviction, or an unwarranted acquittal. Clearly, any expert providing such evidence must assess the uncertainty of the test result (false negative/false positive reporting rates) and express that uncertainty in a format that the jury can be reasonably expected to understand.

9 Validation approaches

9.1 Tests that might be performed to assess the reliability of survey methods include:

9.1.1 Repeatability; Consistency of output of the survey method

- Tests as to whether the tool is consistent with its own output at a different time, or other identical devices at the same time
- The 'true' answer does not need to be known as it is a straightforward comparison of output from different tools that is being performed. While the 'accuracy' cannot be measured (as the true answer is unknown), the differences in output can be assessed and hence a comparison of the uncertainty of measurements can be made. In this example, this is one possible measure of the 'precision' of the device.

9.1.2 Use of Call Data Records (CDRs) as a "trial" of the survey method

- Calls may be made by an individual and the call data records requested from the relevant telecomm service provider.
- This approach tests the equipment against the same situation it is likely to be deployed in live casework. At least one 'true' answer is known, i.e. if the cell that was used at the time of the call is detected using the equipment under test as serving where the call took place this is clearly a valid result.

9.1.3 Stress Testing and bulk data assessment

- Deployment of the survey method in areas where results are likely to be influenced by unusual local factors (e.g. at the edge of service)
- Assessment of general trends in the data

9.1.4 A combination of these tests have been deployed in the assessment of the ICS-500 and the Nemo Walker Air handsets.

10 Methods Assessed

10.1 Nemo Walker Air handsets are engineering handsets, mobile phones with modified firmware such that some factors transmitted by the network, and measurements used by the handset in cell selection and reselection are logged to a specific GPS co-ordinate and recorded. The handsets themselves have SIM cards in them, authenticate on the network, are capable of making calls etc. and are to all intents and purposes are mobile phones directly comparable to those encountered in casework. Devices of this nature have been available (and used) for decades by telecommunication engineers for network maintenance and measurement purposes, and are in established use within forensic examinations for cell site analysis.

10.2 The ICS-500 is a software controlled radio. It does not have a SIM card, does not authenticate on networks, and is not capable of making or receiving calls. It constantly scans all networks and on all available technologies (in this assessment on GSM, UMTS and LTE) approximately once every couple of seconds. Large amounts of data are provided, a line for each cell monitored with associated data decoded (and calculations, e.g. c1 and c2 values for GSM cells) for each measurement. In this way "top cell" data for each technology and band is automatically calculated, along with all other cells detected during that measurement. The results, as presented, are not separated by network and so post processing is required prior to use in an assessment. The post processing used within the validation exercise outlined in this paper was to take each point ID and to select the highest ranked cell for each network and technology at that point. This is referred to as the "top cell" (as opposed to the "serving cell" of an engineering handset, but analogous to it). The other cell details of non-"top cells" are analogous to "neighbour data", that some phone (or phone emulator) survey devices report; this additional data is not reviewed in greater detail in this paper but may be the focus of future work.

10.3 Both types of device were deployed in parallel with each other, in vehicle based surveys of the type outlined elsewhere in this paper

11 Comparison of survey results against "ground truth" Call Data Records

11.1 Survey results from the methods under test were compared to Call Data Records for mobile devices, these call events generated when the location of the device was known. The aim of these tests was to gain a clear understanding of the "false negative" rate of the survey equipment i.e. whether a cell known to serve at the CCL laboratory from the call data was not detected by a given piece of survey equipment. Call Data Records were generated over a two-week period, and those call events taking place while the device making the call was at the CCL laboratory extracted. Calls were made on every UK Mobile Network (O2, Vodafone, "3" and Everything Everywhere), and included Voice Calls, Text Messages and GPRS events (the GPRS events stimulated by a range of activity). The devices making the calls were unlocked (i.e. not forced on to any specific technology, band, channel or cell). Call events on all networks and technologies were present in the call data

11.2 This part of the assessment compared all data from a pre-defined route surrounding the laboratory and compared the totality of the data recorded.

- All 6 Nemo Walker Air devices were deployed in each survey, all monitoring a single network and technology.
- There was only one ICS-500 available for test; the ICS-500 was deployed in parallel with the Nemo handsets for each survey run. The results from the ICS-500 for a single run were compared with the results from the Nemo handsets from the same run (i.e. when the Nemo handsets were surveying O2 GSM, the results for O2 GSM from the ICS-500 for that specific run were compared with those from the Nemo handsets)

11.3 This approach has a number of virtues. At least one 'true' answer is known, i.e. if the cell that was used at the time of the call is detected using the equipment under test as serving where the call took place this is clearly a valid result. Perhaps the most commonly required use for a survey is to assess

- whether a specific cell serves an area including a location
- what cells are detected as serving at a location

This test directly assesses the accuracy of the method used to answer this question

11.4 Only one cell can be recorded as a serving cell in a call record at a given time (although a given call event can have a different end cell to that on which a call started on). There are likely to be several legitimately serving cells at a location [ref 3] and these cannot all be in the Call Data Record for a single event. Selection of any of these other, legitimate, additional cells by the test equipment is therefore not an "incorrect" answer, but as these other 'correct' answers cannot be specified in advance it may not be clear if the method is actually functioning as hoped. This approach is therefore unlikely to highlight false positives (i.e. finding an invalid cell in the test output) but may spot false negatives (artificially excluding a legitimately serving cell).

- If a legitimately serving cell (i.e. the cell in the Call Data Records) is not detected at the location where it is known to have served, additional assessment may therefore be required. For example, the approach adopted for deployment of the equipment may be at fault (some methods are known to be more prone to false exclusions than others) or there may be some other reason (e.g. the cell in question may have been off air at the time of the test survey). As such, even blind trials cannot be definitive and are not used in isolation from other validation approaches.

11.5 The test results are illustrated in Table 1 and Table 2. Within these tables I refer to the "top" ranked ICS-500 cell on the given technology as the "serving cell". The Cellsites used are illustrated in Map 1

11.6 As can be seen in these maps and tables, the ICS-500 consistently performed equal to, and usually better than, the Nemo engineering handset survey solution in the false negative assessment

11.7 99.9% of the calls on the O2 network were handled by cells indicated by the ICS-500 as the "top" cell in the surveys. All six of the Nemo Walker Air handsets also detected 99.9% of the cells used on the O2 network

11.8 100% of the calls on the Vodafone network were handled by cells indicated by the ICS-500 as the "top" cell in the surveys. There was variability within the results for the engineering handsets. All six of the Nemo Walker Air handsets also detected 83.4% of the cells used on the Vodafone network. If overlaid, or "stacked", cells are taken into account (i.e. if a cell originating on the same mast with the same technology was used as an indicator as to whether a cell serves), the Nemo Walker Air handsets also detected 99.7% of the cells used on the Vodafone network

11.9 98.3% of the calls on the "3" network were handled by cells indicated by the ICS-500 as the "top" cell in the surveys. If "overlaid cells" were taken into account, the ICS-500 detected 99.2% of cells on the "3" network. There was variability within the results for the engineering handsets. All six of the Nemo Walker Air handsets also detected 81.2% of the cells used on the "3" network. If overlaid cells are taken into account, the Nemo Walker Air handsets also detected 98.3% of the cells used on the Vodafone network

11.10 82.7% of the calls on the "EE" network were handled by cells indicated by the ICS-500 as the "top" cell in the surveys. If "overlaid cells" were taken into account the ICS-500 detected 99.5% of cells on the "EE" network. There was variability within the results for the engineering handsets. All six of the Nemo Walker Air handsets also detected 78.2% of the cells used on the "EE" network. If "overlaid cells" were taken into account (i.e. if a cell originating on the same mast with the same technology was used as an indicator as to whether a cell serves) the Nemo Walker Air detected 86.6% of cells on the "EE" network

11.11 The ICS-500 successfully detected some of the cells used in the trial when a number of the Nemo Walker Air handsets failed to do so:

- The ICS-500 detected Vodafone UMTS Cell ID 62788 (used 100 times out of 613 listed Cell IDs) when only two of the six Nemo Walker Air handsets did so
- The ICS-500 detected Vodafone GSM Cell ID 09681 (used twice out of 613 listed Cell IDs) when only five of the six Nemo Walker Air handsets did so
- The ICS-500 detected "3" UMTS Cell ID 57232 (used 86 times out of 533 listed Cell IDs) when only five of the six Nemo Walker Air handsets did so
- The ICS-500 detected "3" UMTS Cell ID 57126 (used 3 times out of 533 listed Cell IDs) when only one of the six Nemo Walker Air handsets did so
- The ICS-500 detected "EE" UMTS Cell ID 56563 (used 16 times out of 647 listed Cell IDs) when only two of the six Nemo Walker Air handsets did so
- The ICS-500 detected "EE" LTE Cell ID 4839937 (used 3 times out of 647 listed Cell IDs) when only one of the six Nemo Walker Air handsets did so

11.12 While less prone to falsely excluding legitimately serving cells than any individual handset, the performance of the ICS-500 was not perfect. Both the ICS-500 (and some or all of the Nemo handsets) failed to detect some of the more sparsely used cells in the blind trials

- The ICS-500 and all of the Nemo Walker Air handsets failed to detect O2 GSM Cell ID 12545 (used once out of 877 listed Cell IDs)
- The ICS-500 and all of the Nemo Walker Air handsets failed to detect "3" UMTS Cell ID 43129 (used 3 times out of 312 listed Cell IDs, twice as GPRS cells, once as an end cell for a voice call)
- The ICS-500 and all of the Nemo Walker Air handsets failed to detect "EE" GSM Cell ID 11401 (used 10 times out of 647 listed Cell IDs). Cells on other technologies (UMTS and LTE) based on this mast and with the same azimuth were detected both as top ranked cell by the ICS-500 and as a serving cell by all six Nemo handsets
- The ICS-500 and five of the six Nemo Walker Air handsets failed to detect "EE" GSM Cell ID 11402 (used 3 times out of 647 listed Cell IDs). Cells on other technologies (UMTS and LTE) based on this mast and with the same azimuth were detected as a top ranked cell by the ICS-500 and as a serving cell by some, but not all, Nemo handsets

11.13 There was one occasion when a serving cell was detected by one of the 6 Nemo devices deployed but not by the ICS-500

- "EE" GSM Cell ID 11402 (used 3 times out of 647 listed Cell IDs) was detected as a serving cell by one (but not all) of the 6 Nemo devices

11.14 Both the ICS-500 and Nemo consistently detected nearly all (99%-100%) of the cells used in the trial data if "overlaid cells" (cells based on the same mast and with the same declared azimuth) are taken into account.

12 Assessment of Consistency – Comparison of results between surveys

12.1 The aim of these tests was to gain a clear understanding of whether similar results are returned by similar equipment at the same time or the same equipment at different times. All 6 Nemo Walker Air devices were deployed in each survey, all monitoring a single network and technology (e.g. Everything Everywhere, locked to GSM). The comparison therefore allows comparison between 6 identical, simultaneously deployed, devices. Only one ICS-500 was available for test at a given time. This device was therefore deployed on multiple occasions, and the results were compared between three different runs over the same area. A second ICS-500 unit was supplied and tested at a later date, and the results of an all-network, all-technology survey compared against both the original "ground truth" CDRs and the original set of ICS-500 survey results

12.2 Call Data Records were generated over a two-week period at a single location of interest (there was difficulty in obtaining Call Data Records for testing purposes, which prevented us from specifying a second location from which to repeat the tests). The CDRs were assessed for call events taking place while the device making the call was at the CCL laboratory and were the same as for the "accuracy" assessment outlined above. A circle of circumference 200 metres was used as the sample area, and statistics generated from the data within this area. Three consistency comparisons were made

- GSM consistency on the "Everything Everywhere" network
- UMTS consistency on the "3" network
- LTE consistency on the Vodafone network

12.3 The output of the ICS-500 and engineering handsets (up to six Nemo test handsets) were compared to each other, along with any information available from the network. Where a match was found to exist for the serving cell as detected by the ICS-500 and a survey handset, this was deemed an acceptable result. Where discrepancies exist between the data sets these were investigated further. Tests as to whether the tool is consistent with its own output at a different time were performed. This approach has a number of virtues:

- The 'true' answer does not need to be known as it is a straightforward comparison of output from different methods.
- While the 'accuracy' cannot be assessed (as the true answer is unknown), the differences in output can be assessed and hence a comparison of the uncertainty of measurements can be made. This is related to the 'precision' of the device.

12.4 The test results are illustrated in Map 1. Within this table I refer to the top ranked ICS-500 cell on the given technology as the "serving cell"

12.5 For the "Everything Everywhere" GSM network**.** When the data for the six Nemo handsets was amalgamated, five cells were detected as serving within 150 metres of the CCL Laboratory.

- GSM Cell ID 11398 was the most commonly detected serving cell (3,167 of 3,319, or 95% readings) of the amalgamated Nemo engineering handset measurements. It was consistently the most commonly detected top cell by the ICS-500 on every run (between 83% and 92% of all readings), and the most commonly selected serving cell by each of the six Nemo handsets (between 92% and 99% of all readings). Cell ID 11398 was the most commonly used EE GSM cell in the call data
- GSM Cell ID 9205 was the joint second most commonly detected serving cell of the amalgamated Nemo engineering handset measurements (57 of 3,319 or 1.7% of all readings). It was consistently the second most commonly detected top cell by the ICS-500 on every run (between 4% and 8% of all readings), but varied between each Nemo handset (one of the handsets did not detect it as serving at all in rank 2 and rank 3 by the other five Nemo handsets (between 0% and 6.4% of readings by handset). Cell ID 9205 was used in the CDR tests, so failure to detect it as a serving cell is a false exclusion, as outlined above in the "false negative" accuracy tests.
- GSM Cell ID 9193 was the joint second most commonly detected serving cell of the amalgamated Nemo engineering handset measurements (57 of 3,319 or 1.7% of all readings). It was the consistently the third most commonly detected top cell by the ICS-500 on every run (between 2% and 5% of all readings), but varied between Nemo handsets (two of the handsets did not detect it as serving at all, the others detected it as rank 2 (between 0% and 3.3% of readings by handset). Cell ID 9205 was used in the CDR tests, so those handsets that failed to detect it as a serving cell were false exclusions, as outlined above in the "false negative" accuracy tests.,
- GSM Cell ID 6405 was the fourth most commonly detected serving cell of the amalgamated Nemo engineering handset measurements (24 of 3,319 or 0.7% of all readings). It varied between the fourth or fifth most commonly detected top cell by the ICS-500 (between 0.7% and 3.7% of all readings), and varied between Nemo handsets (four of the handsets did not detect it as serving at all, the other two detected it as rank 3 (between 1.7% and 2.6% of readings by handset). Cell ID 6405 was not used in the CDR tests, so failure to detect it as a serving cell is not necessarily a false exclusion.
- GSM Cell ID 11402 was the fifth most commonly detected serving cell of the amalgamated Nemo engineering handset measurements (13 of 3,319 or 0.4% of all readings). It was only detected as top cell by one of the ICS-500 runs (0.9% of all readings), and was also only detected by one of the six Nemo handsets (between 0% and 2.4% of readings by handset). Cell ID 11402 was used three times in the CDR tests, so failure to detect it as a serving cell is a false exclusion as outlined above.

- GSM Cell ID 11401 was not detected by any of the Nemo engineering handset measurements (in any of the 3,319 readings). It was only detected as top cell by one of the ICS-500 runs (0.3% of all readings). Cell ID 11401 was used ten times in the CDR tests, so for those handsets that failed to detect it as a serving cell is a false exclusion as outlined above.

12.5.1 The ICS-500 detected three of the five most commonly used "EE" GSM cells in the blind trial data, being used for 85% of calls on EE GSM Cells (12% of calls overall, including UMTS and LTE cells). These three most commonly used cells were detected in the same order of prevalence on each of the 3 runs. All of the "EE" GSM cells used in the blind trial were detected on one of the three runs (run 2). The two cells not reliably detected (Cell ID 11401 and 11402) accounted for 15% of the GSM cells used in the blind trials, but only 2% of the cells used overall on that network (as cells UMTS and LTE were also used in the blind trials). One additional cell, Cell ID 6405, was also detected on every run but was not used in the blind trials

12.5.2 The Nemo Walker Air was more variable in its results. Only one EE GSM Cell (Cell ID 11398) was reliably detected by all six of the Nemo handsets. This cell detected at the same position of prevalence, and used for 76% of the calls on "EE" GSM Cells. One cell (Cell ID 9205) was detected by 5 of the 6 Nemo devices, and was used for 12% of the calls on "EE" GSM Cells. One cell (Cell ID 9193) was detected by 4 of the 6 Nemo devices. One Cell (Cell ID 11402) was detected by only one of the six 6 Nemo devices. One additional cell, Cell ID 6405, was detected on 2 of the 6 Nemo devices but was not used in the blind trials

12.5.3 In summary, if the amalgamated Nemo Walker Air survey results (originating from engineering handsets) are compared to each run of the ICS-500,

- The results from the ICS-500 are more consistent with the amalgamated Nemo survey results than each individual Nemo handset is with the amalgamated results
- The results from the ICS-500 are more consistent with itself on each run than the Nemo handsets are with each other

12.6 For the "3" UMTS network. When the data for the six Nemo handsets was amalgamated, eleven cells were detected as serving within 150 metres of the CCL Laboratory. Many of the Cell IDs detected in the surveys were known overlaid cells (i.e. from the CDRs are known to be Cell IDs transmitted from the same mast and on the same azimuth but on different UARFCN's). If the overlaid cells are treated as single entities, the following mast name/ azimuths were detected:

- "Dependent Site of 28690" with an azimuth of 240° (Cell IDs 56963, 57231 and 57232). These were the three most commonly used "3" UMTS cells in the blind trial CDRs, collectively used in 58% of all call events. One or more of Cell IDs 56963, 57231 or 57232 were detected in each of the three ICS-500 surveys and also on all of the six Nemo Walker Air handsets
- "Dependent Site of 28727" with an azimuth of 120° (Cell ID 57102), used in 16% of all call events in the blind trial CDRs. Cell ID 57102 was detected in a similar position

of prevalence in each of the three ICS-500 surveys. Cell ID 57102 was detected in a different positions of prevalence on each of the six Nemo Walker Air handsets

- "Dependent Site of 28727" with an azimuth of 240° (Cell IDs 57103 and 57030), collectively used in 23% of all call events. Cell IDs 57103 and 57030 were both detected (in different positions of prevalence) in each of the three ICS-500 surveys
- "Dependent Site of 28690" with an azimuth of 90° (Cell IDs 56953, 57120 and 57126), collectively used in 3.1% of all call events. Cell IDs 56953 and/or 57126 were detected (in different positions of prevalence) in each of the three ICS-500 surveys. Cell ID 57120 was not detected as top cell in any of the ICS-500 surveys. Cell IDs 56953 and/or 57126 were detected (in different positions of prevalence) by only two of the six Nemo Walker Air handsets, and Cell ID 57120 was not detected as a serving cell by any of the six Nemo handsets; Four of the six Nemo handsets failed to monitor any of the overlaid cells for this mast and azimuth
- "EVESHAM ROAD CEMETERY 216492" with an azimuth of 20° (Cell ID 43129), used in just 0.6% of all call events in the blind trial CDRs. Cell ID 43129 was not detected as a top-ranked cell in any of the three ICS-500 surveys, or by any of the Nemo handsets. The cellsite was visited at a later date and the cell was on air at that time; while there is no guarantee it was on at the time of the survey data under consideration, the survey results for all six Nemo handsets and the ICS-500 appear to have failed to detect a legitimately serving cell

12.6.1 Three additional cells were detected by the ICS-500 on every run in addition to those occurring in the blind trial CDRs (Cell IDs 8867, 8924 and 9053). All three of these cells were also detected by one or more Nemo handset, and hence would only be "false positives" for the software controlled radio if they were also false positives for the engineering handsets

12.6.2 The ICS-500 consistently detected 7 of the 10 "3" UMTS cells used in the trial data. These cells were the three most commonly used cells in the blind trial data, being used for 97.2% of calls on "3" UMTS Cells. All six of the Nemo handsets consistently detected 4 of the 10 "3" UMTS cells used in the trial data. These cells were the three most commonly used cells in the blind trial data, being used for 59.7% of calls on "3" UMTS Cells. Only UMTS cells were used on the "3" network blind trials), and many of these most commonly used cells were overlaid (i.e. with the same mast location and azimuth in the CDR but transmitted on different carriers)

12.6.3 In summary, if the amalgamated Nemo Walker Air survey results (originating from engineering handsets) are compared to each run of the ICS-500,

- The results from the ICS-500 are more consistent with the amalgamated Nemo survey results than each individual Nemo handset is with the amalgamated results
- The results from the ICS-500 are more consistent with itself on each run than the Nemo handsets are with each other

12.7 For the Vodafone LTE network, when the data for the six Nemo handsets was amalgamated, two Vodafone LTE cells were detected as serving within 150 metres of the CCL Laboratory.

12.7.1 The ICS-500 detected Vodafone LTE Cell ID 130870814 at the highest prevalence on each of the 3 runs. All six of the Nemo handsets also detected Vodafone Cell ID LTE 130870814 at the highest prevalence. Cell ID 130870814 was the only Vodafone LTE cell used in the trial data

12.7.2 Two additional cells were also detected on every run but were not used in the blind trials for call data generated at CCL. Cell ID 133248010 was detected as the second most prevalently detected cell on all three ICS-500 surveys. This cell was also detected by all six of the Nemo handsets. Cell ID 133248010 is known to be based on a mast at CV379NU on azimuth 0°, along with Vodafone UMTS Cell ID 62105. It is reasonable, therefore, that this cell is not a "false positive". Cell ID 131211274 was detected on all three ICS-500 surveys. Cell ID 131211274 is known to be based on a mast at CV370JA on azimuth 120°, along with Vodafone GSM Cell ID 09681 and UMTS Cell ID 62298, both used by mobile phones when known to be at CCL. It is reasonable, therefore, that this cell is also not a "false positive", even though it was not detected by the engineering handsets. Cell ID 131293706 was detected as the third most prevalently detected cell on the first of the ICS-500 surveys but not on the others. It is not known where the cell was based. It was measured as top cell for 2 of 151 measurements (1.3%); It is not yet known if this cell is a "false positive"

12.7.3 In summary, if the amalgamated Nemo Walker Air survey results (originating from engineering handsets) are compared to each run of the ICS-500,

- The results from the ICS-500 are more consistent with the amalgamated Nemo survey results than each individual Nemo handset is with the amalgamated results
- The results from the ICS-500 are more consistent with itself on each run than the Nemo handsets are with each other

12.8 In overall summary, the performance of the ICS-500 was equal to, and usually better than, the Nemo Walker Air Handsets in consistently replicating results for each technology tested. The ICS-500 reported more Cell IDs, and more consistently, than the Nemo handsets. There is no obvious evidence that suggests that the ICS-500 falsely includes cells that do not legitimately provide service.

13 Stress Testing and Bulk Data review

13.1 A Stochasticity assessment has been made. Cell selection for a mobile device is dependent on a number of factors, including the average received signal strength (and, according to technology used, the quality of the received signal) and network-received conditioning information [ref 10]. As a result, co-located mobile phones can select different cells as servers at a given time and place, and will tend to "hang on" to those cells for a period of time [ref 3]. The cell selected by a mobile device from those that are capable of serving at a given moment is therefore not a truly random ("stochastic") process as it may depend to some extent on the history of previously selected cells.

13.1.1 Measurements from a single survey on the O2 GSM network were compared between the ICS-500 and 3 Nemo handsets (unlocked, but all measurements on 900MHz). The area surveyed included rural, suburban and urban (including city centre) locations, including wide areas as well as detailed overdrives of specific locations in and around the city of Coventry. The locations of the measurements assessed are presented in map 2 and the results of this assessment are presented in Table 3. As can be seen in this table, the ICS-500 selected 140 Cell IDs as "Top Cell", as opposed to between 113 and 125 for the Nemo handsets. When all of the data for the Nemo handsets was amalgamated, there were 137 different Call IDs selected for service by one or more of the 3 handsets. One of the Nemo handsets (the N97) failed to select 23 of these Cell IDs, the "slave 1" failed to select 19 and the "slave 2" failed to select 11. The ICS-500 failed to select 12 of them, and also selected an additional 4 Cell IDs as top cell that none of the three Nemo devices selected as a serving cell. The frequency of change was significantly higher for the ICS-500 than for any of the Nemo devices, with approximately three times as many cell changes by the ICS-500 than any of the Nemo devices in the same period, even at a sampling rate of approximately half that of an individual Nemo handset. The ICS-500 was less prone to "hang on" to cells and this was despite the ICS-500 having a smaller number of measurements (21,522, as opposed to between 35,287 and 37,672 for each individual handset, or 109,271 readings between all Nemo handsets). Given that it is an expectation that there will be multiple cells able to provide service at a specific location, this is a strong indication that the ICS-500 provides a more complete indication of serving cells when comparing "top cell" with serving cell information. Two of the three Nemo handsets were demonstrably more prone to falsely excluding known serving cells than the ICS-500 and the third was approximately equivalent. This was despite GSM surveys being the least complex in terms of monitoring carriers.

13.2 A handset can only select a single cell at a given time, and this cell will be on a single carrier. The carrier, and hence the cell, that is selected will be dependent on a number of factors including but not restricted to the cell previously selected, the activity of the device and potentially even the tariff of the subscriber. These details will be unknown in an analysis, and hence ensuring that a survey device is monitoring the most relevant carriers during a survey is problematic. An obvious potential advantage of a Software Controlled Radio approach is that, unlike a handset, it is not constrained to presenting measurements from a single carrier for a given reading. These issues do not really apply to the GSM network, which tends to be almost exclusively used for voice calls and text messages and for which "start cell" call events almost always originate on 900MHz cells for O2 and Vodafone and 1800MHz cells for EE. The carriers monitored were compared between the Nemo engineering handsets and the ICS-500.

13.2.1 For 3G networks multiple carriers are available, the number of which is dependent on the network under consideration, and only some of which may be deployed in an area. From comparative review of case data, typical observed patterns include situations such as 4 sets of carriers available on the O2 network, all 4 of which were monitored by the ICS-500 but only 3 in the amalgamated Nemo data.

13.2.2 For 4G networks multiple carriers are available (the number of which is dependent on the network under consideration) and only some of which may be deployed in an area. From comparative review of case data, the Nemo handset data contained some apparently contradictory information concerning 4G channels so comparison was difficult. After taking into account some of this uncertainty, typical observed patterns include situations such as 10 sets of carriers available on the EE network, 9 of which were monitored by the ICS-500 but 7 in the amalgamated Nemo data – it is unknown if all 10 carriers were in use).

13.2.3 The Nemo handsets are capable of monitoring all of the carriers, but they only present data for a single carrier at a time. Ensuring that the most relevant carrier (i.e. that which the suspect phone was using when alleged to be at the location) is being monitored in a given set of readings would require additional information potentially unavailable to the practitioner. Acting on this information would also require additional activity (e.g. use of locking to specify the carrier to be monitored, itself a potentially controversial approach as, for example, we don't know how the carriers are prioritised for selection by the suspect phone). The ICS-500, while only presenting a single top cell in the method adopted for this assessment, also presents data for other carriers as part of the same measurement

13.3 Discrepancies between engineering handset results and ICS-500 readings have been investigated. The ICS-500 was deployed in parallel with the engineering handsets with a view to highlighting locations where the results between the two approaches differed markedly. These circumstances were then subjected to additional detailed review.

13.3.1 One such example was within a large park on the edge of a city (Sutton Park, in Birmingham, one of the largest urban parks in Europe). At the location of interest within this park the ICS-500 detected as top cell an "Everything Everywhere" LTE cell on band 7 that a simultaneously deployed Nemo handset did not. The Nemo handset did not detect any serving LTE cell on band 7 at that location and, on closer examination of the data, the received signal strength readings of the ICS-500 were very low, leading to additional analysis concerning the relative sensitivity of the devices as outlined below. This had the effect of the apparent service area of the band 7 cell being apparently greater using the ICS-500 data than if using the Nemo data. A similar set of circumstances were encountered for a UMTS cell in southwest Birmingham extending into a rural area; again, this was a low signal strength "edge of service" for the carrier under consideration, and the same concerns apply

13.3.2 There were no specific case examples encountered where the GSM survey data was markedly different to that from the engineering handsets requiring more detailed assessment. Given the experiences as outlined above concerning UMTS and LTE cells on the edge of service, survey data was assessed with regards to low received signal strengths. There were no examples of very low signal strengths being encountered in the "top cell" ICS-500 data, but there were examples when wider data was considered (RSSI values between -105 and -110dBm, and even some below -110dBm). Some of these readings (for non-"Top" cells) were below the known RxLevAccessMin value, and so these cells would have been automatically excluded for consideration by a handset with the same information.

13.4 As a result of the assessments above, more detailed consideration was given to the sensitivity of the devices used in the validation exercise. The ICS-500 was deployed in parallel with the Nemo devices, with the ICS-500 antenna deployed on the roof of the vehicle, with the Nemo handsets being inside. The results for each serving Cell ID detected on the Nemo handset and the Received Signal Received Power for each UMTS cell was compared between the handsets and the ICS-500. While there was some variability, the received power was nearly always greater on the ICS-500 device, often by 10dB or more.

13.4.1 Tests were performed to compare performance with survey devices inside and outside the vehicle. There was an observed reduction in received signal strengths by situating survey devices (both the Nemo handsets and the ICS-500) inside a vehicle rather than outside it, but no noticeable difference in the cells selected.

13.4.2 Given that a mobile device is making a relative decision when selecting a serving cell, this difference in sensitivity makes little difference in areas that have acceptable received signal strengths on a given carrier; the difference in sensitivity would apply to all of the cells considered and thus not advantage one cell over the others.

13.4.3 The effect of differences in sensitivity at or approaching the edge of service of a given network/ technology/ band would be as observed in the case examples above, with the ICS-500 more likely to indicate a greater range of a given cell on the edge of service of its carrier than those engineering handsets under test. Assessing whether there is actual service from the cell in question at these locations may require additional consideration, and this may be difficult to fully resolve

13.4.4 The comparisons were for a vehicle based survey and the instances where significant differences were detected between the devices were at the edge of service. We do not know where a suspect device was, but if a user was in a low service area and trying to make a call, it is not unreasonable behaviour to move around attempting to find the best signal in a manner that could not be replicated in a survey. We also do not know what the sensitivity of the suspect device was, and it may be better than the Nemo handsets used in the survey. As such, the enhanced sensitivity of the ICS-500 is not necessarily a disadvantage, but data at the edge of service should, in the view of the authors, be considered with greater caution than for other circumstances.

14 Summary, conclusions and recommendations

14.1 Survey data does not stand alone, and needs a wider structure within which it is used to provide safe inference:

- The forensic strategy within which the survey is used is dependent on case circumstances, and may vary according to the wider purpose of the examination.
- Survey equipment is used as part of a wider survey method (i.e. the equipment is one part of a process, how the equipment is used is also important to the process).
- Survey data is subject to uncertainty, and a practitioner must understand this uncertainty. Survey data is used in conjunction with other information to form a technical opinion.
- Presentation of technical opinions concerning service of cells as a series of piecemeal observations in isolation of each other and the wider purpose of the examination is dangerous and inappropriate. The survey must be embedded in a wider process addressing whether the CDR would be expected given the positions taken by prosecution/ defence or to present possible explanations for the data if acting in investigative mode.

- While the survey data may be "fact", inferences drawn from that data will not be; Survey data should therefore be used to inform, not define, opinion.
- Survey data can form part of a "Presumptive test", for example as an initial exercise to highlight those cells observed to serve at a location but, if these results are to be used in an evidential context (e.g. to presented at court) they should be tested in the context of the matter to be addressed by the court, which will consider wider information than just individual, technical observations. This should be addressing whether the call data might be expected given propositions, for example using the AFSP standard for evaluative evidence, as part of consideration of the entirety of the call data in the CDR.
- There is a danger in assuming that just because a survey tool acts like a mobile phone, it will act like another phone being used at the same place and time, or – more relevantly – like the suspect mobile phone did at the time it generated the CDRs considered. This is a demonstrably false assumption and must be avoided.

14.2 Survey data can be used to inform opinion on whether specific cells do, or do not, serve at specific locations or to provide an estimation of their service areas as part of a wider consideration of the call data against the specified propositions. To provide safe inference, uncertainties in the data considered should be known, quantified as much as is reasonable and then accommodated within the assessment of specific case circumstances being considered. Uncertainties in CDRs are one consideration an expert must be aware of, and so are those in the survey data. There is no such thing as a perfect survey method that the authors are aware of, so limitations of methods used should be measured and accommodated if used in provision of opinion on the wider call data

14.3 Engineering handsets are an established method, and have an inherent credibility over other types of other survey tool as they are mobile phones, therefore act as mobile phones, and most Cell Site Analysis exercises consider data generated by mobile phones. There is a hidden danger in taking such data at face value, however. Just because a survey tool acts like a mobile phone, it does not mean that it acts like another phone being used at the same place and time, or – more relevantly – like the suspect mobile phone did at the time of the calls considered. As a phone can only select a single cell at a given time, and tends to hang onto it, they are prone to falsely excluding legitimately serving cells and this applies to the suspect's phone as much as the engineering handset used in a survey. Aspects of this limitation might be accommodated by for example locking to carriers, but even this approach doesn't fully solve the issue, as demonstrated by the Stochasticity assessment (for which only one set of carriers were used). Locking is also time consuming and anecdotally has greater potential for false inclusion of cells that don't serve. An obvious advantage of an engineering handset is that connected mode cells can be measured, in a way that Software Controlled Radio cannot replicate.

14.4 Use of Software Controlled Radio for forensic cell site analysis is a new method which attempts to address these shortcomings. The ICS-500 has different advantages and disadvantages to engineering handsets. While there is still no absolute assurance that this equipment will detect all cells, it has the ability to monitor different carriers simultaneously. Overlaid ("stacked") cells were more reliably detected by the ICS-500 than Nemo handsets. Use of survey data for overlaid cells demonstrably reduces the false negative rate concerning potentially falsely excluding legitimately serving cells. While there may be concerns that Call Data records may, on occasion, provide data with incorrect azimuths, failure to accommodate overlaid cells in an analysis is also a demonstrable source of potential error. Use of additional network information (cell queries) and/or analyses to ascertain overlaid cells is therefore an obvious route to reduce the false-negative rate (N.B. even this would not have reduced the false negative rate for use of survey results to zero). The ICS-500 is of greater use than an engineering handset in excluding cells from potentially serving at a location. There are a number of elements to this, including that:

- The ICS-500 monitors multiple carriers simultaneously, but also presents data for cells that are considered, but not highlighted as a "top cell". There is more data immediately available for consideration than within the Nemo data
- Within that additional data, specific fields may be present that can provide greater assurance of "non-service". For example, on GSM the ARFCN of the cell of interest may be decoded as being used by a different cell at the location of interest. Under these circumstances it would not be reasonable to use the original cell under consideration in the CDR at that location; the ICS-500 more reliably decodes and presents this type of data

14.5 It is therefore recommended by the authors that wherever possible, engineering handsets and SCR devices are deployed in parallel. This gives the "best of both worlds" approach of particular use when the results between them are different. This may not always be possible (for example, there are many networks and technologies under assessment and there are not enough engineering devices available to deploy). In these circumstances, the ICS-500 does not provide obvious "false positive" results and so, in the view of the authors, the survey data can be relied on, except potentially at the edge of service where, in the view of the authors, the data should be considered in fine detail as part of an expert assessment.

14.6 It is emphasised by the authors that the purpose of the survey exercise is to inform a wider expert assessment of call data; it is recommended that survey data not be presented in isolation of this wider process.

14.7 A likelihood ratio is a broadly accepted approach to handling uncertainty, and work on this approach is in progress [ref 20]. The work presented within this paper is intended to assist in additional development of this type of model.

15 Acknowledgements

The authors would like to thank Simon Iveson, Paul Kilby and Eoghan Casey for discussion and constructive input on this paper.

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Network	Cell ID	Azimuth	Site Name	Postcode	Cell Tech	Start Count CS	End Count CS	GPRS Count	Total	%	QRC	Nemo	Overlaid Cell
O2	14188	120	STRATFORD UPON AVON N.W.	CV37 0JA	3G	0	0	1	1	0.1%	✓	6/6	1
O2	15487	0	SHOTTERY	CV37 9NU	2G	1	0	1	2	0.2%	✓	6/6	2
O2	34097	355	STRATFORD UPON AVON WEST	CV37 9SY	3G	89	100	114	303	34.5%	✓	6/6	
O2	21640/ 32214	355	STRATFORD UPON AVON WEST	CV37 9SY	3G	98	67	43	208	23.7%	?	?	
O2	130870914	355	STRATFORD UPON AVON WEST	CV37 9SY	4G	43	0	113	156	17.8%	✓	6/6	3
O2	130870918	355	STRATFORD UPON AVON WEST	CV37 9SY	4G	3	0	42	45	5.1%	✓	6/6	
O2	32545	355	STRATFORD UPON AVON WEST	CV37 9SY	2G	79	62	20	161	18.4%	✓	6/6	
O2	12545	110	STRATFORD UPON AVON WEST	CV37 9SY	2G	1	0	0	1	0.1%	×	0/6	4
						314	229	334	877		99.9%	99.9%	

Network	Cell ID	Azimuth	Site Name	Postcode	Cell Tech	Start Count CS	End Count CS	GPRS Count	Total	%	QRC	Nemo	Overlaid Cell
Vodafone	09681	120	SnitterfieldCV370JA	CV370JA	2G	1	0	1	2	0.3%	✓	5/6	1
Vodafone	62298	120	SnitterfieldCV370JA	CV370JA	3G	4	3	2	9	1.5%	✓	6/6	
Vodafone	62105	0	StratfordUponAvonCV379NU	CV379NU	3G	1	2	0	3	0.5%	✓	6/6	2
Vodafone	07582	355	StratforduponAvonCV379SY	CV379SY	2G	41	38	15	94	15.3%	✓	6/6	
Vodafone	62788	355	StratforduponAvonCV379SY	CV379SY	3G	51	36	13	100	16.3%	✓	2/6	
Vodafone	62791	355	StratforduponAvonCV379SY	CV379SY	3G	41	32	6	79	12.9%	✓	6/6	3
Vodafone	63042	355	StratforduponAvonCV379SY	CV379SY	3G	66	83	65	214	34.9%	✓	6/6	
Vodafone	130870814	355	StratforduponAvonCV379SY	CV379SY	4G	0	0	112	112	18.3%	✓	6/6	
						205	194	214	613		100.0%	83.4%	

Network	Start Cell ID	Start Azimuth	Start Site Name	Start Postcode	Start Cell Tech	Start Count CS	End Count CS	GPRS Count	Total	%	QRC	Nemo	Overlaid Cell
"3"	57102	120	Dependent Site of 28727	CV37 0QT	3G	37	24	24	85	15.9%	✓	6/6	1
"3"	57030	240	Dependent Site of 28727	CV37 0QT	3G	23	20	12	55	10.3%	✓	6/6	2
"3"	57103	240	Dependent Site of 28727	CV37 0QT	3G	21	31	14	66	12.4%	✓	6/6	
"3"	43129	20	EVESHAM ROAD CEMETERY 216492	CV37 9JE	3G	0	1	2	3	0.6%	×	0/6	3
"3"	56953	90	Dependent Site of 28690	CV37 9RL	3G	3	1	2	6	1.1%	✓	6/6	
"3"	57120	90	Dependent Site of 28690	CV37 9RL	3G	1	2	3	6	1.1%	×	0/6	4
"3"	57126	90	Dependent Site of 28690	CV37 9RL	3G	4	1	0	5	0.9%	✓	1/6	
"3"	56963	240	Dependent Site of 28690	CV37 9RL	3G	60	34	18	112	21.0%	✓	6/6	
"3"	57231	240	Dependent Site of 28690	CV37 9RL	3G	51	35	23	109	20.5%	✓	6/6	5
"3"	57232	240	Dependent Site of 28690	CV37 9RL	3G	45	22	19	86	16.1%	✓	5/6	
						245	171	117	533		98.3%	81.2%	

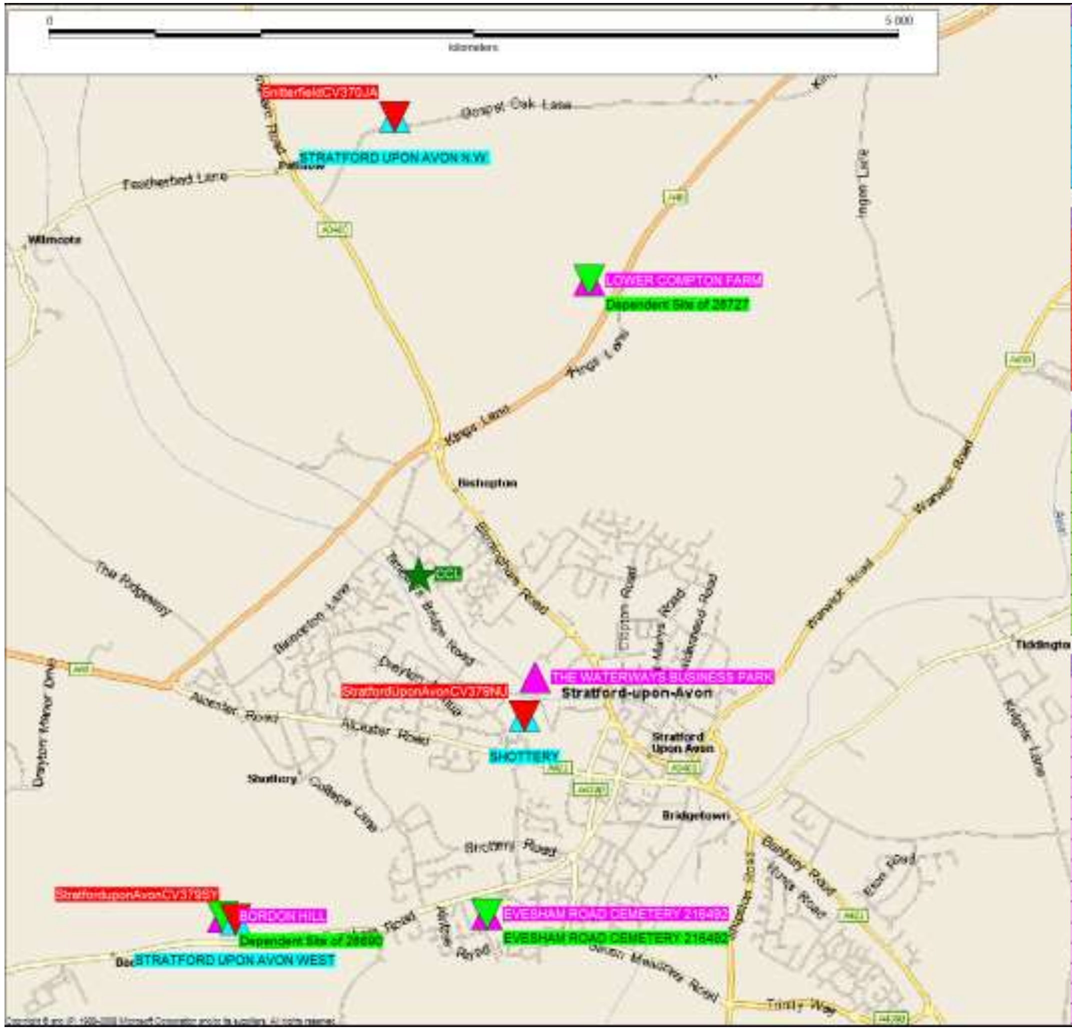
Table 1; Blind Trial Results for O2, Vodafone and "3" networks

Co-located cells/ azimuths are grouped by colour, those cells highlighted in red represent cells which were not detected as serving by some devices in the survey

Network	Start Cell ID	Start Azimuth	Start Site Name	Start Postcode	Start Cell Tech	Start Count CS	End Count CS	GPRS Count	Total	%	QRC	Nemo	Overlaid Cell
"EE"	4846080	30	THE WATERWAYS BUSINESS PARK	CV37 0AB	4G	0	0	3	3	0.5%	✓	6/6	1
"EE"	09205	330	THE WATERWAYS	CV37 0AB	2G	3	0	1	4	0.6%	✓	6/6	2
"EE"	09193	240	LOWER COMPTON FARM	CV37 0QT	2G	3	0	0	3	0.5%	✓	6/6	3
"EE"	56901	240	LOWER COMPTON FARM	CV37 0QT	3G	22	12	7	41	6.3%	×	0/6	
"EE"	57139	240	LOWER COMPTON FARM	CV37 0QT	3G	33	37	45	115	17.8%	✓	6/6	
"EE"	4843010	240	KINGS LANE	CV37 0QT	4G	2	0	40	42	6.5%	✓	6/6	
"EE"	12838	20	EVESHAM ROAD CEMETERY 216492	CV37 9JE	3G	0	1	0	1	0.2%	×	0/6	4
"EE"	4683520	20	EVESHAM ROAD CEMETERY	CV37 9JE	4G	0	0	2	2	0.3%	×	0/6	
"EE"	11398	30	BORDON HILL	CV37 9RL	2G	47	4	14	65	10.0%	✓	6/6	5
"EE"	11402	90	BORDON HILL	CV37 9RL	2G	2	1	0	3	0.5%	×	1/6	6
"EE"	56563	90	BORDON HILL	CV37 9RL	3G	3	6	7	16	2.5%	✓	3/6	
"EE"	56847	90	BORDON HILL	CV37 9RL	3G	11	10	0	21	3.2%	×	0/6	
"EE"	4839937	90	BORDON HILL	CV37 9RL	4G	0	0	3	3	0.5%	✓	1/6	
"EE"	11401	330	BORDON HILL	CV37 9RL	2G	9	0	1	10	1.5%	✓	0/6	7
"EE"	56547	330	BORDON HILL	CV37 9RL	3G	47	38	49	134	20.7%	✓	6/6	
"EE"	56782	330	BORDON HILL	CV37 9RL	3G	15	17	12	44	6.8%	×	0/6	
"EE"	4839936	330	BORDON HILL	CV37 9RL	4G	35	0	105	140	21.6%	✓	6/6	
						232	126	289	647	100.0%	82.7%	78.2%	

Table 2; Blind Trial Results for the "EE" networks

Co-located cells/ azimuths are grouped by colour, those cells highlighted in red represent cells which were not detected as serving by some devices in the survey



Network	Cell ID	Azimuth	Site Name	%	QRC	Nemo
O2	14188	120	STRATFORD UPON AVON N.W	0.1%	✓	6/6
O2	15487	0	SHOTTERY	0.2%	✓	6/6
O2	34097	355	STRATFORD UPON AVON WEST	34.5%	✓	6/6
O2	21640/ 32214	355	STRATFORD UPON AVON WEST	23.7%	?	?
O2	130870914	355	STRATFORD UPON AVON WEST	17.8%	✓	6/6
O2	130870918	355	STRATFORD UPON AVON WEST	5.1%	✓	6/6
O2	32545	355	STRATFORD UPON AVON WEST	18.4%	✓	6/6
O2	12545	110	STRATFORD UPON AVON WEST	0.1%	×	0/6

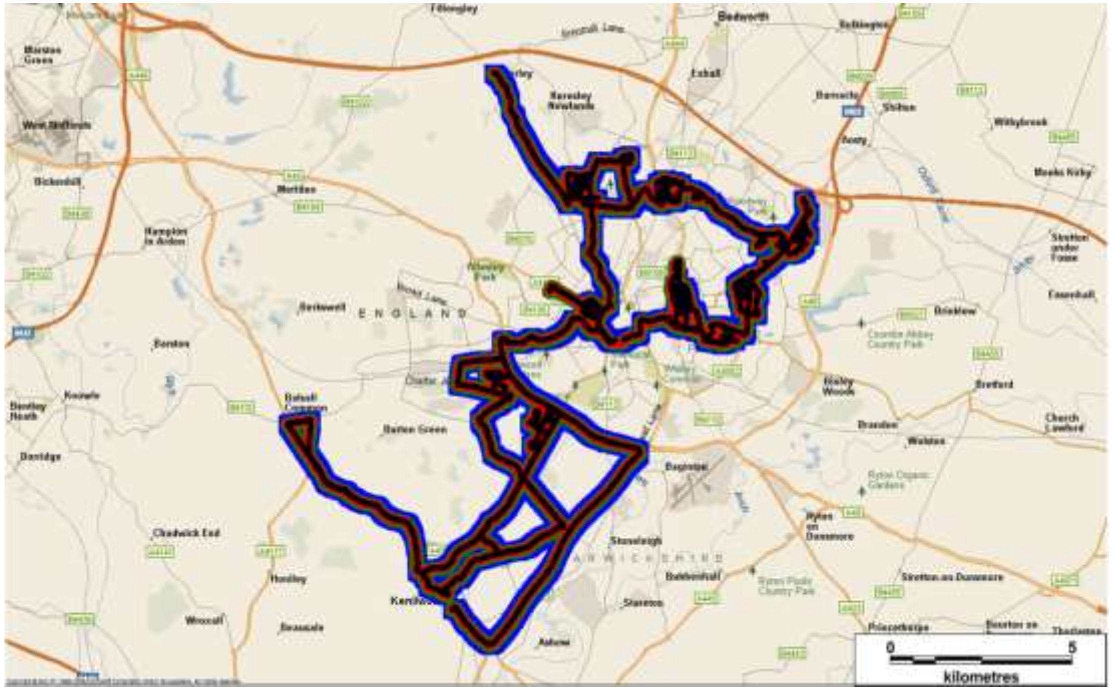
Network	Cell ID	Azimuth	Site Name	%	QRC	Nemo
Vodafone	09681	120	SnitterfieldCV370JA	0.3%	✓	5/6
Vodafone	62298	120	SnitterfieldCV370JA	1.5%	✓	6/6
Vodafone	62106	0	StratfordUponAvonCV379NU	0.5%	✓	6/6
Vodafone	07582	355	StratforduponAvonCV379SY	15.3%	✓	6/6
Vodafone	62788	355	StratforduponAvonCV379SY	16.3%	✓	2/6
Vodafone	62791	355	StratforduponAvonCV379SY	12.9%	✓	6/6
Vodafone	63042	355	StratforduponAvonCV379SY	34.9%	✓	6/6
Vodafone	130870814	355	StratforduponAvonCV379SY	18.3%	✓	6/6

Network	Start Cell ID	Start Azimuth	Start Site Name	%	QRC	Nemo
"3"	57102	120	Dependent Site of 28727	15.9%	✓	6/6
"3"	57030	240	Dependent Site of 28727	10.3%	✓	6/6
"3"	57103	240	Dependent Site of 28727	12.4%	✓	6/6
"3"	43129	20	EVESHAM ROAD CEMETERY 216492	0.6%	×	0/6
"3"	56953	90	Dependent Site of 28690	1.1%	✓	6/6
"3"	57120	90	Dependent Site of 28690	1.1%	×	0/6
"3"	57126	90	Dependent Site of 28690	0.9%	✓	1/6
"3"	56963	240	Dependent Site of 28690	21.0%	✓	6/6
"3"	57231	240	Dependent Site of 28690	20.5%	✓	6/6
"3"	57232	240	Dependent Site of 28690	16.1%	✓	5/6

Network	Start Cell ID	Start Azimuth	Start Site Name	%	QRC	Nemo
"EE"	4846080	30	THE WATERWAYS BUSINESS PARK	0.5%	✓	6/6
"EE"	09206	330	THE WATERWAYS	0.6%	✓	6/6
"EE"	09193	240	LOWER COMPTON FARM	0.5%	✓	6/6
"EE"	56901	240	LOWER COMPTON FARM	6.3%	×	0/6
"EE"	57139	240	LOWER COMPTON FARM	17.8%	✓	6/6
"EE"	4843010	240	KINGS LANE	6.5%	✓	6/6
"EE"	12838	20	EVESHAM ROAD CEMETERY 216492	0.2%	×	0/6
"EE"	4683520	20	EVESHAM ROAD CEMETERY	0.3%	×	0/6
"EE"	11398	30	BORDON HILL	10.0%	✓	6/6
"EE"	11402	90	BORDON HILL	0.5%	×	1/6
"EE"	56563	90	BORDON HILL	2.5%	✓	3/6
"EE"	56847	90	BORDON HILL	3.2%	×	0/6
"EE"	4839937	90	BORDON HILL	0.5%	✓	1/6
"EE"	11401	330	BORDON HILL	1.5%	✓	0/6
"EE"	56547	330	BORDON HILL	20.7%	✓	6/6
"EE"	56782	330	BORDON HILL	6.8%	×	0/6
"EE"	4839936	330	BORDON HILL	21.6%	✓	6/6

Map 1; Cells present in the Call Data records when the phone generating them was known to be at CCL

Cellsite locations are represented by triangles. Co-located cells/ azimuths are grouped by colour, those cells highlighted in red represent cells which were not detected as serving by some devices in the survey



Map 2 – Stochasticity assessment; Route Surveyed (Coventry)

	ICS-500	N97	Walker Air Slave 1	Walker Air Slave 2
Period	08:32:26 to 16:22:01	08:31:22 to 16:20:56	08:28:41 to 16:19:15	08:23:50 to 16:31:24
Number of Data Points	21522	36312	35287	37672
Number of Cell Changes	1470	454	489	524
% Of cell Changes	6.8%	1.3%	1.4%	1.4%
Number of Different Cells	140	113	117	125
Number of Different Cells	140	137 with amalgamated data from all 3 Nemo devices		