USING CELLULAR TELEPHONES TO TRACK PARTICIPANTS' MOVEMENTS TO AND FROM AN EVENT

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ABSTRACT

The aim of this project was to determine whether the cellular telephones of spectators could be tracked actively while travelling to and from an event, to give them useful travel information *en route*. Further, we investigated the effect on the tracking results when a large number of people attend such an event, creating cellular telephone network congestion. It was envisaged to map the movements in real-time to link them to a spatial traffic information system, to correlate a participant's route with any traffic incidents, such as congestion or accidents. The advisory based on the aforementioned would then be sent as a computer-generated voice message to the participant. Owing to the unavailability of such a system, the advisory was simulated by the participants themselves, by sending text messages that were then broadcast as voice calls, as a proof of concept. The event selected was a sell-out Super 14 rugby game, which provided the required congested network. The network bounced the cellular telephones around the nearest cells to the stadium, thus detaching the inferred location of the cellular telephone from the actual spatial location of the participant. It was possible to track participants travelling at speed with reasonable accuracy, but not possible to track pedestrians owing to canyon effects. It was also not possible to track participants close to the event owing to the cell bouncing.

INTRODUCTION

Arising out of an experiment that we conducted in March 2005 (Krygsman and Schmitz, 2005), we initiated a more comprehensive project, *GenDySI, Generation and harnessing of DYnamic Spatial Intelligence* (long title: *Building a shared spatial data knowledge platform to harness real-time geocoded information of transport-spatial interaction*). One of the GenDySI pilot projects was the *Event Personal Travel Advisor (E-PTA)*, which aimed at active tracking of the cellular telephones (cell phones) of individuals going to and from an event, to provide them with useful information on current traffic conditions and directions to appropriate parking, etc. Such events could be sports events, pop concerts or festivals, or anything likely to draw a significant crowd. The intention was that the messages would be computer-generated voice messages sent to the cell phones of the participants. A further objective was to test what impact a very large crowd would have on cellular network congestion, as this could severely limit the utility of tracking cell phones at an event with a large crowd (Cooper *et al*, 2009; Cooper *et al*, 2010). The hypothesis was that as one approached the event and got deeper into the crowd, the mass of cell phones would overload the cells closest to the venue and cell phones would then be bounced outwards to less congested cells. Hence, one could get the anomaly that as someone moved towards an event, the tracking would show their cell phone moving away from the event. Needless to say, such a phenomenon would severely limit the utility of tracking cell phones at an event with a large crowd.

Initially, the concept was to perform active tracking in real-time and to link the results on a geographical information system (GIS) with traffic data from a metropolitan authority. The plan was to determine the route and direction of each participant and combined with the real-time traffic data, advise the participant about the traffic conditions along their route towards the event. Unfortunately, at that time none of the metropolitan authorities had a functioning live spatial traffic information system – their live traffic data was very similar to what is broadcast over the radio in traffic reports. Hence, we decided to simulate this by having the participants (project members, colleagues and friends) generate the traffic reports themselves. The event we selected for E-PTA was the Super 14 rugby match at Loftus Versveld between the Bulls and the Cheetahs, on Saturday 10 February 2007. Fortunately, there was a sell-out crowd.

TRACKING

The technology involved in this project is the use of cellular networks and cellular telephones. The cellular service providers break an area up into cells to provide cell phone coverage. This is done using a base station (antenna), which is either an omni-directional antenna (an antenna located in approximately the middle of the cell) or a directional antenna (an antenna that transmits into a cell). Figure 1 shows the concept. Hexagons are used for planning purposes, but in reality the shape of the cell is influenced by the terrain (Lee, 1986). Cellular service providers are allocated a specific frequency band in the 900 MHz and 1800 MHz range and use two techniques to enable the service provider to provide a service for millions of subscribers. These two techniques are cell splitting and frequencies re-use (Lee, 1986).

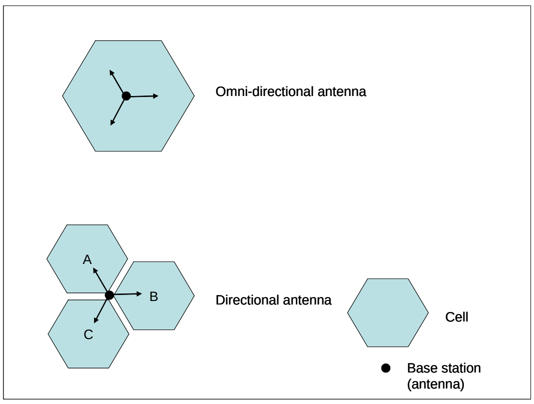

Figure 1: Two types of base stations (antennas) used by cellular service providers.

Frequencies re-use is where cells at different geographic locations use the same frequency, but are far enough from each other not to cause interference. Cell splitting is used to break up an existing cell into smaller cells to enable it to handle higher amounts of traffic (Lee, 1986).

The cellular telephone system used in South Africa is the GSM (Global System for Mobile communications) system, which was developed in Europe in the early 1980s (Scourias, 1999). The GSM network can be divided into three broad entities, namely the mobile station, the base station subsystem and the network subsystem as illustrated in Figure 2 (Scourias, 1999).

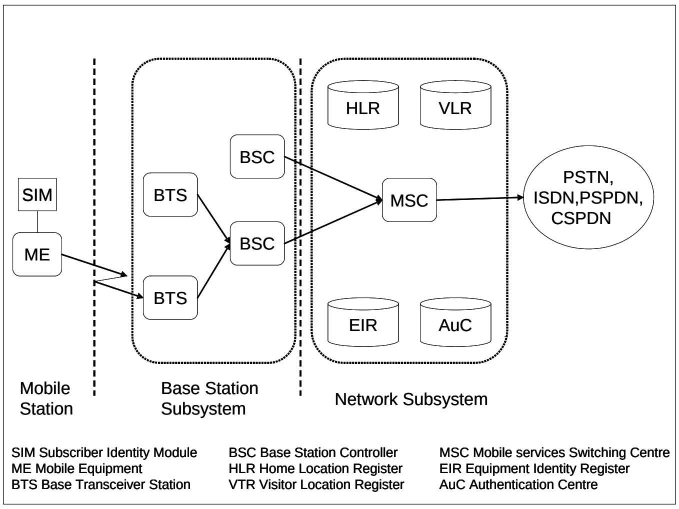

Figure 2: General architecture of a GSM network (from Figure 1, Scourias, 1999)

To enable the tracking of a cell phone for the purpose of the study, the cell phone must be powered on. The cellular service provider sends a blind SMS (Short Message Service) to the cell phone. The cell phone is informed of the incoming SMS on the control channel using the HLR, VLR and MSC. Once the MSC located the cell phone via the BSC in a cell of a BTS, using information from the HLR, VLR, and MSC, the traffic channel is made available for the data to be sent. With a blind SMS, the SMS is stopped just before the traffic channel is made available. The control channel provided the location of the cell phone by giving the Cell ID, which is then linked to a coordinate pair along with the subscriber number, time and date (Scourias, 1999 and Abouchabki, 2005). For the purpose of this project, a blind SMS is referred to as a “ping”; and when sending a blind SMS it is known as “pinging”.

Using the date-time data the next ping location can be determined. This information needs to be captured in the data set as FromPing and ToPing. For snapping the interaction to the nearest road network the Cell ID in the FromPing column must be different to Cell ID in the ToPing column. If the FromPing Cell ID is the same as the ToPing Cell ID it indicates that the handset was stationary and will be omitted from the snapping exercise. These interactions between two consecutive ping locations are snapped to the nearest road network as illustrated in Figure 3. The snapping of the interaction to the nearest road network is done using Flowmap, a software package developed by the University of Utrecht’s Faculty of Geosciences. It is dedicated to analysing and displaying flows (movement) between users (customers) travelling to facilities or services (Geertman *et al*, 2003).

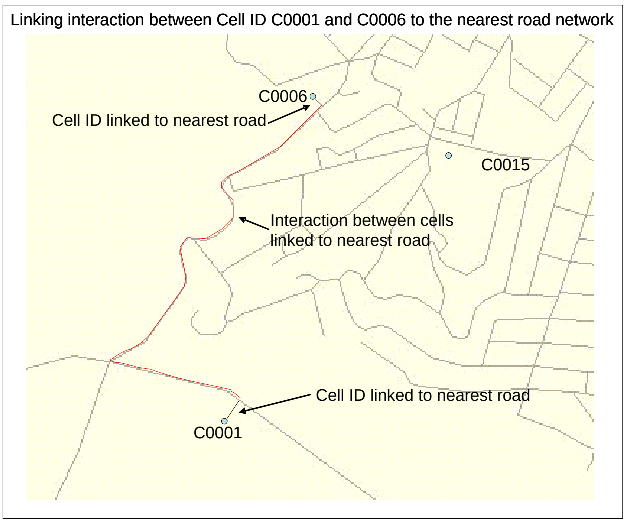

Figure 3: Snapping the interaction to the nearest road network (from Schmitz and Cooper, 2007).

MESSAGING

The MobilEd (Mobile Education) platform is a multi-faceted communications server that allows the transmission of electronic information across various channels, for example an audio telephone call or SMS. It was originally designed to enable the usage of a public information source, such as the Wikipedia on-line encyclopaedia, via a cell phone. This is accomplished by employing technologies such as text-to-speech (TTS) engines and interactive voice response (IVR) applications, along with standard text-based messaging services (Aucamp *et al*, 2007).

For querying Wikipedia, for example, a user sends an SMS query to the MobilEd server, after which the server responds by calling back the user and delivering the requested article contents via text-to-speech. It is on a per-request basis; that is, every SMS request results in one telephone call back to the sender's number.

The GenDySI E-PTA project required a way for the E-PTA system to automatically inform drivers of traffic conditions and problems in their area, using the drivers' cell phones as the media. Although text-based options such as SMS or MMS (Multimedia Message Service) might at first seem to be the best solution, these require the driver of a vehicle to read the message from the screen of his/her phone, thereby distracting his/her attention from driving. Furthermore, it does not necessarily provide real-time updates, as the user might not immediately open and read the message, effectively rendering it useless. Taking these facts into account, the only viable solution is making a standard audio telephone call to the driver of the car. The driver, making use of a hands-free kit, would answer the incoming call, and an appropriate traffic update message would be read to him/her using either a TTS engine (for dynamic, unassisted content) or a recording (for content moderated by human operators). Apart from answering the phone, no interaction is required from the driver – this allows him/her to concentrate on driving the vehicle.

For the E-PTA pilot, it was decided that passengers in the participating cars would interact with the system, so that the drivers would not be distracted. These passengers would send text-based traffic updates to the system using SMS; these updates would then be read to the passengers via the aforementioned telephone call-mechanism. Therefore, the system requires the ability to receive and respond to incoming SMSs, make telephone calls, and read the contents of the SMSs to the participants of the pilot. The original MobilEd platform met these requirements to a certain degree; for instance, the physical SMS/telephony communications were already in place, but they were geared toward delivering educational content (such as an encyclopaedia article) to a single user at a time. Furthermore, MobilEd makes use of existing free and open-source software components for low-level communication, such as the Asterisk software PBX (Private Branch Exchange) for telephony and the Kannel SMS Gateway for text messaging; as such, it is relatively cheap and easy to reproduce the system at different locations, and it is well-aligned with the CSIR's strategy of supporting and advocating the use of open-source software (Aucamp *et al*, 2007).. The E-PTA pilot also represents a new and unique application for these communications platforms.

The required message flow for the E-PTA platform is depicted in Figure 4, below. A user would send an SMS containing the traffic update to the server, after which the server phones all users participating in the event, and reads the message via text-to-speech. Figure 4 illustrate how this procedure looks from the user's point of view. In Figure 4, User 1 sends an SMS containing the traffic update. After receiving the SMS message, MobilEd transforms the message into audio using text-to-speech, and initiates several simultaneous audio telephone calls to all of the users participating in the event.

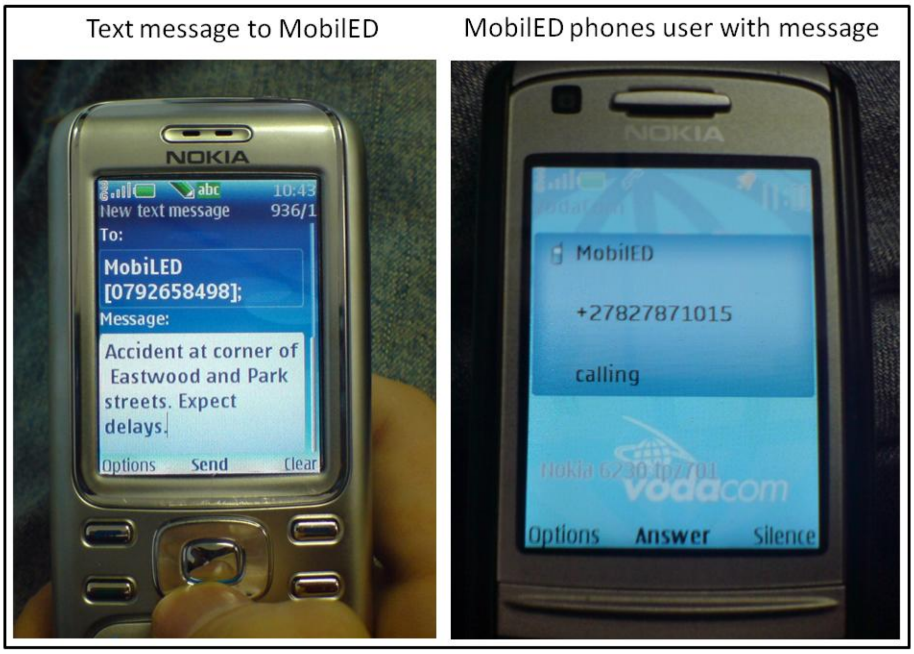

Figure 4: MobilED usage from different user view points.

RESULTS

Ten cell phones were tracked: one used by a participant who walked to the event, and the other nine by participants who were driven to the event. The latter were paired off with a driver, so that the participant could focus on the requirements of the project, without needing to drive. All the participants were briefed on the project and signed informed consent forms (Cooper *et al*, 2009). To establish how accurate the tracking was, each participant (scribe) kept a travel diary describing their route by way of way points and times. These were compared to the cell phone tracks to assess their accuracy and to refine the Flowmap model used to generate them. The scribes also submitted and monitored traffic reports (as described below). Some of the routes coincided very well with the travel diary routes, while others did not. The modelled route of the walking participant (Participant 8, lower right map in Figure 5) was poor: this is because there is a dense network of cells along his route and at walking pace, the distance he moved between pings would be much shorter and hence, his phone would bounce around between different cells on either side of his route. The tracking of pedestrians needs further research work. The tracking of participants travelling long distances or at highway speed was accurate: see Figure 5.

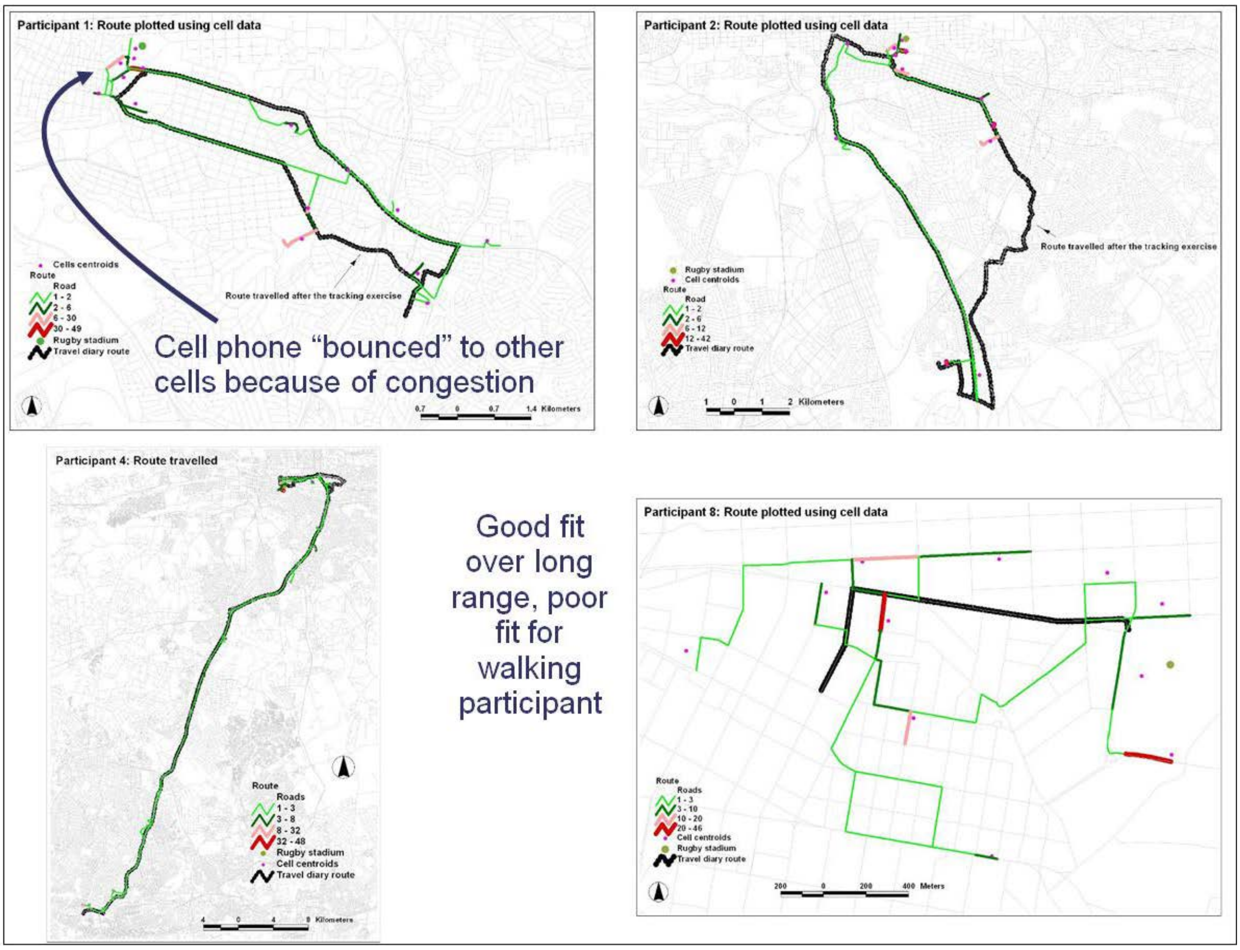

Figure 5: Examples of routes based on tracking results.

Our tracking data around the venue revealed that there was congestion on the network, as we anticipated, but our phones were bounced around different cells in close proximity to the venue, rather than being bounced further and further away from the venue, as shown by the results for Participants 1 and 2 in Figure 5. Hence, while it is possible to track cell phones to and from an area where there is congestion on the network, it is not possible to track cell phones once they are in the area of congestion, because their movement between cells is not necessarily connected to their physical movement.

Figure 6 shows some "errors" in the Flowmap generated route compared with the actual route taken by Participant 10. The reasons are that the locations of the cell centroids that were activated caused a loop as shown in the bottom part of Figure 6. The "detour" shown at position number 6 in Figure 6 was the result of a missing road section in the road data set used in the modelling of the route. The second "detour" at position number 11 is due to the location of the cell centroid that was activated during the tracking and Flowmap routed the route as close as possible to the location of the centroid. In general the results of this proof-of-concept are promising and need further research to refine the Flowmap modelling.

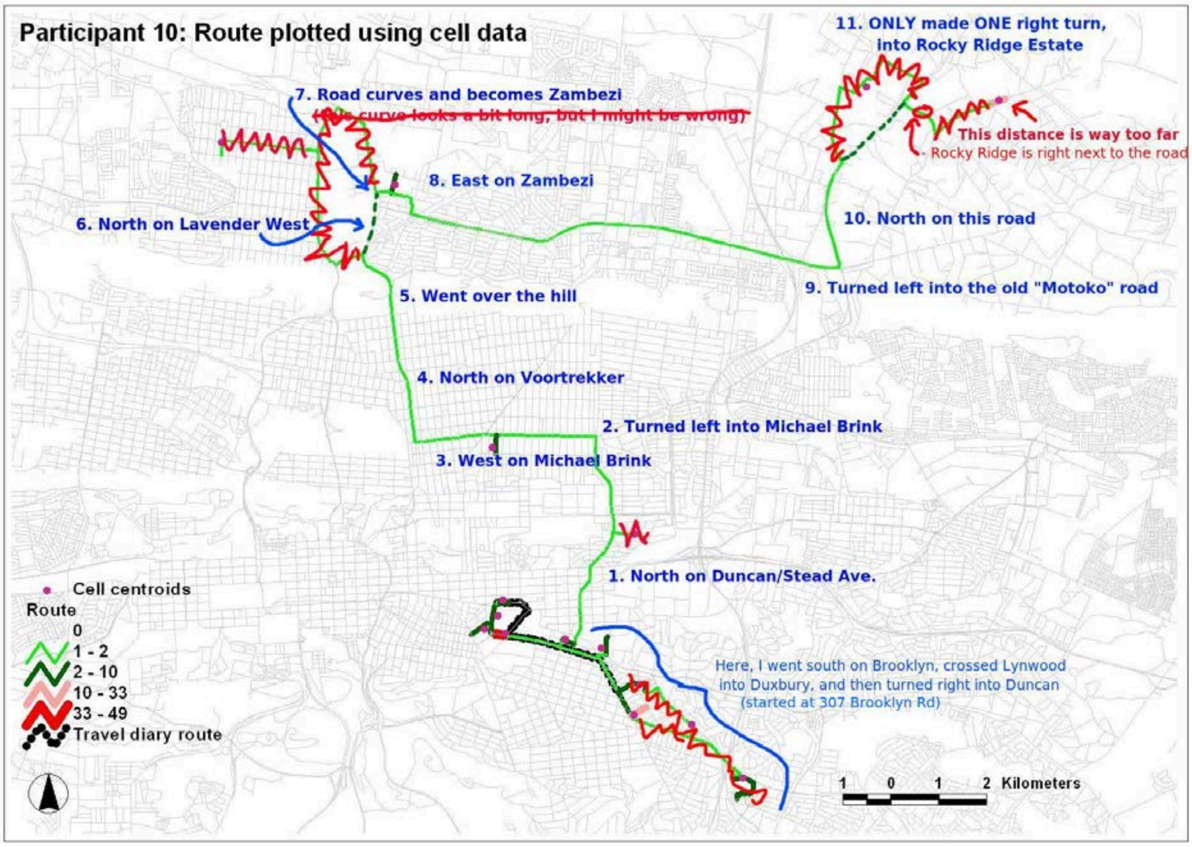

Figure 6: The annotated modelled route of Participant 10.

Figure 7 shows a three dimensional (3D) visualisation of the routes travelled by each participant. This is known as a space-time graph showing participants activity through space and time. This concept was developed by Swedish geographers in the 1960s and 1970s (Hagget, 1979) and further developed by Kraak (2003) using GIS. The figure illustrates the converging of the participants at the sporting event and the dispersion of the participants after the event. This is similar to a study conducted by Asakura and Hato (2005), who tracked individuals going to, and leaving from, a sumo wrestling contest.

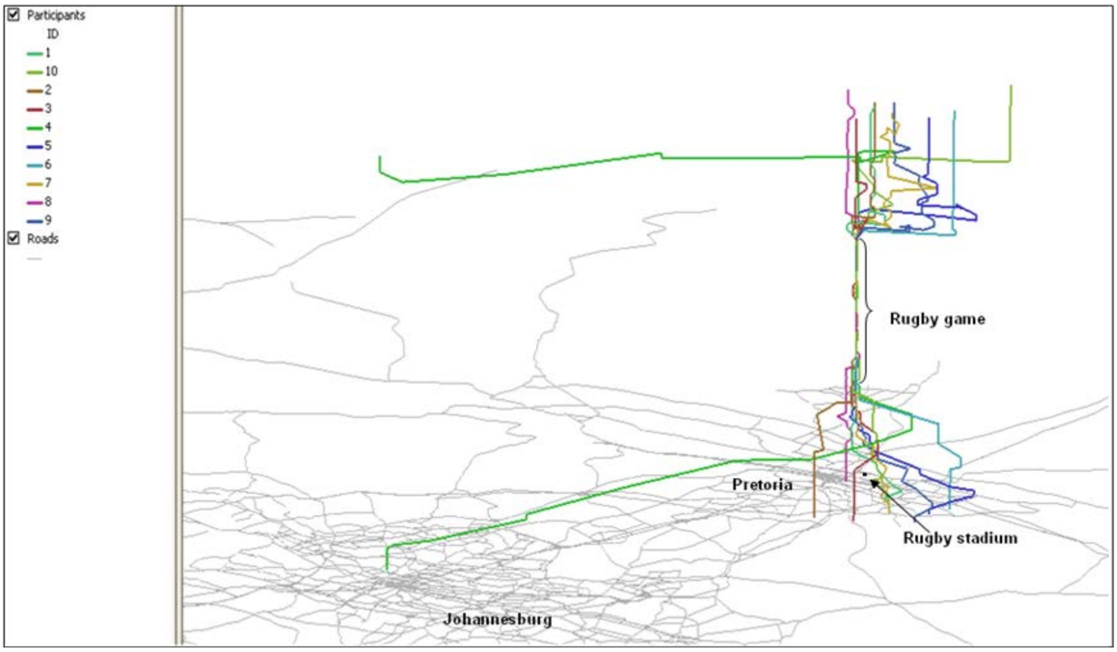

Figure 7: The routes of the participants shown in 3D.

FUTURE WORK

Based on the experienced gained in this project and a review of the literature, possible research applications are:

- Tracking tourists or event spectators using assisted GPS such as those found in cellular telephones. Shoval and Isaacson (2006) made a comparison between GPS, assisted GPS and cellular triangulation. Assisted GPS (A-GPS) are normal GPS devices that make use of a cellular network to improve their location performance. This is helps to position the GPS in built-up areas where the satellite signals are weak (Zahradnik, 2011). Their study showed that both GPS and assisted GPS give good results. Since assisted GPS devices in cellular telephones are becoming more common, it shows huge potential to track tourists and spectators. Assisted GPS has the potential to eliminate the bouncing of cellular telephone between towers owing to congestion. Assisted GPS even has the potential to place a spectator in the correct seating block in a stadium. However, GPS tracks could still be subjected to canyon effects, where line of sight to the GPS satellites is obstructed by tall buildings or trees.
- Tracking vehicles as they travel through dangerous areas, such as mountain passes subjected to severe weather conditions, to provide traffic alerts via voice calls to the drivers of those vehicles.
- Using the above technologies, TB patients or other patients can be tracked in order to assist them in finding the nearest clinics or hospitals to obtain the necessary medication. This will reduce the patient’s dependency on a specific clinic or

hospital to receive the required medication. Shoval, *et al* (2008) discusses the tracking of Alzheimer patients using assisted GPS technology.

- The Flowmap models can be refined further to provide better snapping of the tracking results to the road network.
- Research is needed on the types of voices and messages that are appropriate for sending voice messages to drivers, particularly bearing in mind the ethical issues – which in themselves need further research.

CONCLUSION

This study was a proof-of-concept to illustrate an alternative method to gather movement data from participants other than detailed travel diaries or GPS devices that track the movement. With regards to cellular telephones it is possible to triangulate the position using signal strengths from neighbouring base stations. This method however places an additional burden on the network, especially when several individuals are tracked over a lengthy period such as a sport event (Abouchabki, 2005). This was not a viable option, although the accuracy would have been much higher. It was then decided to track individual cellular telephones as discussed in this paper.

Although there was no real-time tracking of the participants in this study, E-PTA demonstrated the ability to track participants to and from an event. Thus it is possible to track participants in real-time and provide the necessary information to participants with regards to traffic conditions to and away from an event. Further, E-PTA has shown that cell bouncing is a problem with tracking at events, but it is still possible to track cell phones until they reach the area of network congestion. However, the process of distributing voice messages to participants did work; though more work needs to be done on the type of voices and messages that are appropriate, particularly bearing in mind the ethical issues – which in themselves need further research.

In general it proved to be a viable alternative to obtain travel data with the exceptions as illustrated in the paper which needs further research to improve accuracy. If the tracking of the participant can be enhanced with secondary information provided by the participant as shown in Figure 6 it could be of use in travel studies. Secondary information could include places of work, recreation, shopping, residence, etc. as well as why certain routes were used by the participant.

A preliminary version of this paper was presented at IFORS 2008 [Schmitz *et al* 2008].

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