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Generating Road Traffic Information from Cellular Networks – New Possibilities in UMTS

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Abstract- This paper summarizes different approaches to collecting road traffic information from second-generation cellular systems (GSM) and point out the possibilities that arise when third generation systems (UMTS) are used. Cell breathing is a potential problem, but smaller cells, soft handover and flexible measurements have the potential to increase the usage area and information quality when road traffic information is extracted from the UMTS network compared to using the GSM network.

I. INTRODUCTION

Road traffic is steadily increasing and traffic congestions are getting a part of everyday life for more and more commuters. Traffic congestions are not only an environmental problem, but also a traffic safety problem. Better information regarding traffic congestions can reduce the environmental influence from road traffic by minimising the time spent in queues. Congestion notification can also be used to prevent rear-end collisions.

Road traffic information can be collected in numerous ways, e.g. roadside detectors, public callers, floating car data (FCD) or license plate matching. These methods all have the potential to generate high quality traffic information with different advantages and drawbacks. They all share a common drawback though: the lack of scalability, i.e. it is not economically defendable to implement any of these collection methods over a larger geographical area.

The success of cellular networks and their characteristics introduce a new way of collecting road traffic information. This paper describes different approaches to collecting road traffic information from second-generation cellular systems and the possibilities that arise when third generation systems are used.

II. BACKGROUND

The purpose of a cellular communication system is to offer mobile communication to subscribers of the system. In order to do this the mobile operator has to keep track of where in the network a certain subscriber is located. The location is used to reach the subscriber if it has incoming data transfers and to assign the subscriber to the most appropriate radio base station.

The location within the network can with knowledge of the network structure be transformed to a position of the subscriber, i.e. coordinates. The basic operation of

determining the speed of a vehicle is to measure its location two times and determine the average speed between these two points. Hence, if we could use the cellular network to determine the position of a subscriber at two times we could calculate the average speed of the subscriber between these two points. If we could do this for vehicles travelling on a road network it would be possible to estimate the average speed of vehicles on a certain link.

Estimating travel times by analysing traffic from mobile phones has been subject for research since mid 1990's. This was at a time when telematics services were supposed to expand rapidly within a few years. The cellular networks gave a possibility to communicate with the vehicles, and now it was possible to use it as a source of traffic information too. The foreseen rush of telematics services failed to come and the willingness to pay for such services was much lower than expected. With a rather slow telematics market the interest in traffic information generated by cellular networks was reduced. One of the major problems with the telematics market was, and still is, the lack of quality traffic information and generating traffic information from cellular networks might be a step in the right direction.

The task of determining a detailed position of a user in a cellular network without using dedicated positioning equipment, e.g. a GPS receiver, is challenging. Even with the most sophisticated positioning methods available today and perfect conditions the accuracy will likely not be better than 20 meters. To achieve this relatively high accuracy it is important to keep in mind that scarce bandwidth resources are used every time a position is calculated. However, the possibilities in estimating road traffic information from cellular networks roots from the fact that we are only interested of positions on the road network, several measures are available for each user and a lot of users are travelling a given road section. The first assumption makes map matching possible, which increases the accuracy significantly [1]. The second assumption gives the possibility to determine a specific route for a user. The third assumption gives statistical credibility to the data.

III. LOCATION DATA IN GSM

The backbone in an efficient travel time estimation system is analysis of signalling data generated by users in *busy state*, i.e. during voice calls or data sessions. This signalling data

generated by busy state terminals is in GSM handled by Radio Resource Management (RRM) algorithms located in the radio access network. Complementary data can be obtained from positioning functions in the network (active monitoring) or signalling data generated by *idle state* terminals. Signalling data of idle state terminals is handled by Mobility Management (MM) algorithms located in the core network.

RRM is only active when the terminal is in busy state and an important task of RRM is to initiate handover. The Base Station Controller (BSC) is responsible for the handover decision and use information from measurement reports sent by the terminal and the current Base Transceiver Station (BTS). This information is very useful in the process of tracking a terminal. The terminal and the BTS repeatedly send information about received signal strength (RXLEV) and signal quality in bit error rate (RXQUAL). The fields are 6 bits long and correspond to a resolution of 64 discrete values. The terminal measure the signal quality and strength on the downlink and the BTS measure the signal quality and strength on the uplink. Based on the neighbouring list that is broadcasted by the BTS, the terminal tunes in to neighbouring cells and measure the signal strength. From the terminal, measurement reports are sent on Slow Associated Control Channel (SACCH) once every 480 ms, the BTS adds the uplink measures and forwards a measurement result to the BSC.

Due to the propagation delay from the terminal to the BTS the terminal has to start its transmission earlier in order to avoid interference on adjacent timeslots. When the terminal shall start its transmission is calculated in the BTS and the terminal is informed via a timing advance (TA) value that is sent on the SACCH to the terminal. The TA field is 6 bits long and corresponds to a resolution of 550 m. The TA value can also be used by the BSC in the handover decision and is included in the measurement report from the terminal. The BSC can use the TA value to roughly estimate the terminals velocity and, if an hierarchical cell structure is used, assign highly mobile terminals to an umbrella cell. The TA value is also important for the BSC to complement the signal strength measurements in order to determine which cell to handover the terminal to.

When the terminal is in idle mode, i.e. powered on but not used for voice calls, data sessions or signalling, MM algorithms in the core network keep track of which part of the network the terminal is located. The location information of a terminal in idle mode is much more sparse and has a resolution of Location Area (LA), which consist of a configurable number of cells. The mobile terminal sends an LA update message when it detects a new LA identity broadcasted by the currently strongest BTS. During the LA update the terminal goes into busy state and more location information can be retrieved during a short period of time. A detailed description of GSM MM and RRM can be found in e.g. [2].

A GPRS-attached terminal does also generate location data, the information is however slightly different from circuit switched GSM data. When the terminal is attached to the GPRS network it can be in two mobility management states, *stand-by* and *ready state*. When the terminal is in ready state it can send and receive user data. A major difference between GPRS ready state, compared to circuit switched busy state, is that the terminal itself is responsible for which BTS to communicate with (mobile evaluated handover) [3]. The terminal listen to neighbouring cells during packet transfer and decides if it should stick with the current BTS or change to a better one. In ready state cell identity, TA-value and signal strength to the serving cell is useful location parameters. Since mobile evaluated handover is used, the terminal does not report signal strength to surrounding cells in ready state and this information cannot be used for tracking the terminal. In stand-by state the terminal is connected to the GPRS network, but is unable to send user data. In stand-by state the terminal only performs Routing Area (RA) updates. A RA comprise one or more cells and is comparable to, but not the same as LA.

IV. TRAVEL TIME ESTIMATION TECHNIQUES

Two different approaches can be distinguished when generating traffic information from cellular networks. The first approach is based on the Federal Communications Commission (FCC) mandate that all mobile phones should be possible to locate with certain accuracy. This implies that mobile phones can be located periodically and hence an average speed can be determined for the vehicle. This approach has the drawback that it generates extra traffic in the network and might be more vulnerable to privacy issues. The second approach relies on monitoring the generated traffic without trying to explicitly locate any of the mobile phones. The first approach is referred to as active monitoring whereas the second is referred to as passive monitoring.

Active monitoring can use any of the positioning technologies available today in order to locate a vehicle, e.g. CGI, CGI+TA, E-OTD, U-TDOA, OTDOA, GPS or A-GPS. In passive monitoring it is possible to use all the data generated by the terminal described in the previous section to track a vehicle. The problem with the passive monitoring approach is that terminals only generate detailed location information in busy state. This reduces the number of available probes significantly compared to all mobile phones that are switched on. The hybrid approach is based on passive monitoring with the possibility to complement with active monitoring upon certain criteria, e.g. large variations in estimations and light network load.

The possibility of estimating road traffic information with the help of cellular communication networks is well known, although the technique is not widely used today. Several commercial solutions are available, most of them situated in the U.S.¹. Commercial companies, public organizations and

¹ AirSage, Applied Generics, CellInt, Estimotion, IntelliOne, Makor Issues and Rights

universities have carried out field tests and simulations in order to evaluate the possibilities of the technology. A number of tests have been carried out in the U.S., but field tests have also been carried out in Austria, Canada, China, Finland, France, Germany, Israel, the Netherlands and Spain [4]-[8].

The Cellular Applied to ITS tracking And Location (CAPITAL) project was one of the first attempts to exploit cellular data to extract traffic information. The operational project started in 1994 in Virginia and ran for 27 months. The system used TOA together with AOA positioning to actively monitor different subscribers. The solution is based on active monitoring and it was unable to extract any useful information [7]. Since then a lot of experience has been made in field tests and simulations and a number of projects have reported promising results.

The projects following CAPITAL has taken many different approaches to extracting information from the cellular networks. Good surveys can be found in [4]-[7]. Reference [4] focus on active monitoring, [5] focus on active monitoring and map matching, [6], [7] discuss both active and passive monitoring, where [7] has an extensive list of field test summaries.

Early papers in the area are mainly focused on the active monitoring approach. Also the developed simulation models are based on this approach. Reference [10]-[12] use simulation to evaluate the impact of system parameters, e.g. sampling interval, positioning error etc., in active monitoring based systems. Also [13] is an active monitoring based simulation model, the focus in this paper is to evaluate a segment based approach to estimate travel times.

A number of papers assume configurations to the cellular network in order to generate more detailed signalling traffic [14]-[18]. These systems will be able to estimate the traffic conditions better than standard passive monitoring systems, but it is unclear if the signalling configurations will be implemented in a commercial communication system.

Due to an increasing number of mobile terminals on the roads that generate useful data, a wish to minimize network load and better tracking algorithms, the passive monitoring approach has gained popularity. Two ways of collecting the signalling data from the network are proposed. The first one is based on analysis of billing information sent from the core network. This approach is used in [8], [19]. The billing information is not as detailed as the information available in the radio access network and hence more information is available by listening to an interface of the radio access network. This approach is used in e.g. [9], [20], [21].

The natural extension to use either active or passive monitoring is to combine these two approaches; this is also suggested in recent commercial systems [22]-[24]. It is though unclear from present publications if it has been evaluated in a field test. This approach makes it possible to gather more information when it is most useful without putting unnecessary load on the network.

Whether active, passive or hybrid monitoring is used, a travel time estimation algorithm can include the following basic steps:

1. Location data collection
2. Filtering of fast moving terminals
3. Map matching
4. Possible route determination
5. Travel time calculation

Above these basic steps the algorithm should be able to compensate for anomalies like terminals in a bus with a separate lane, terminals on trains, terminals on motorcycles or bicycles etc. Useful tools to include in the algorithm are statistical analysis, filtering and data mining. To what extent these tools are used is unclear from published literature.

V. 3G DIFFERENTIATING CHARACTERISTICS

As for GSM networks, the mobility of terminals in UMTS networks is handled by MM and RRM functions. MM and RRM are implemented in a similar manner in both systems, there are however a couple of fundamental differences. In UMTS RRM is solely handled by the UMTS Radio Access Network (UTRAN), this is achieved by connecting the Radio Network Controllers (RNC) with each other. Another important difference between the systems is that the support for Quality of Service (QoS) for different service classes in UMTS calls for more adaptive MM. This is solved by implementing MM functions not only in the core network, but also in UTRAN. More information regarding UMTS MM and RRM can be found in e.g. [25], [26].

In both GSM and UMTS the MM state of the terminal decides how much location information that is available. The MM state model in UMTS reminds a lot of the one used in GSM/GPRS, although the UTRAN MM adds a number of new states. Principally the location of the terminal in UMTS is known on cell level and network evaluated handover (NEHO) is used when the terminal is used for a service with high QoS demands (e.g. speech or a high bit rate data session). When the terminal is switched on but not used for data transfer it is known on LA or RA level. When the terminal is used for low bit rate data transfer it is known on cell or UTRAN Registration Area (URA) level depending on mobility.

The location of the terminal is known in most detail when the terminal is used for circuit switched services or high speed data services, i.e. when the UTRAN MM state is *Cell DCH*. In this state NEHO is used, which means that the terminal continuously reports data of the radio connection that can be used to locate the terminal. This state is similar to busy state of circuit switched GSM. The RRM of the two systems are however quite different, which leads to a number of important differences in available information. The main differentiating characteristics of UMTS RRM compared to GSM is:

- Handover control
- Time alignment
- Power control

These functions will affect the available information of a connection. The most important difference in handover control

is the use of soft handover in UMTS. This means that the terminal is connected to several base stations at the same time and the location of the terminal can be determined in more detail. The terminal is expected to be in soft handover during 20-40% of the time [26]. Another difference in handover control is how the network makes the handover decision, i.e. the characteristics of the measurement reports that are sent from the terminal and the base station to the RNC. The measurement reports in UMTS are not only periodic, but can also be event-triggered and requested by UTRAN. Exactly how the reports will be carried out will be implementation specific and dependent on radio conditions. However, [27] states that the terminal shall at least report intra-frequency measurements on up to 32 cells every 200 ms, inter-frequency measurements on up to 32 cells every 480 ms and GSM measurements on up to 32 channels every 480 ms (in compressed mode).

A potential problem with travel time estimation is the use of *cell breathing*, which probably will be more utilised in UMTS than in GSM. In cell breathing the size of the cells can change dynamically depending on the capacity need of different areas. An important tool to determine travel time is to measure the time between handover points, and if cell breathing is used the handover points will change with time. It will hence be more difficult to predict the handover points, but the pilot power of the base stations is known and can be used as input for the predictions.

An important function of CDMA based systems is fast power control. In UMTS the inner loop power control makes it possible to adjust the terminal's power level 1500 times per second [26]. This can be compared to approximately two times per second in GSM. This means that the power level between the terminal and its serving base station(s) is measured at least 1500 times per second, and hence a massive collection of data is available. This data can be used to locate the terminal relative to the connected base station(s) and be useful in the travel time estimation. However, a potential problem is that the inner loop power control is performed in the base station, which means that the information is not available in the RNC where it is viable to collect it. The RNC is though responsible for the outer loop power control, i.e. to control the target signal to interference ratio (SIR), which has a frequency of 10-100 Hz [26].

Reports to support handover and power control will be useful in order to locate the terminal according to relative received power level from different base stations. Power levels might not be the most efficient measurement to use when a terminal shall be located; this is due to fast and shadow fading. More often time differences are used to calculate the position of a terminal, which leads us to the time alignment comparison of UMTS and GSM. As described above, time alignment is important in GSM and is managed with the TA-value calculated by the BTS and sent to the terminal. Since UMTS is a CDMA based system, the time alignment is not needed in order to avoid co-channel

interference and is not implemented. In travel time estimation the TA value is used for estimating the distance between the terminal and a base station, how can we do that in UMTS then?

During soft handover it is important to minimize the buffer needed in the terminal to combine the signal from the base stations. To do this, the terminal measure the time difference between the base stations and send this information to the network, which compensates for this by time alignment of the base station signals. If we know the real-time difference between the base stations, which can be measured by base stations or location measurement units (LMUs), we can narrow down the position of the terminal relative the base stations (cf. TDOA positioning). Another possibility is to use the round-trip time (RTT) measurements calculated by UTRAN. Reference [27] states that the RTT should have a measurement period of 100 ms and an accuracy of ± 0.5 chip. One chip accuracy in time correspond to approximately 80 m. Reference [28] claims however that it is possible to measure RTT with the accuracy of 1/16 of a chip, which corresponds to approximately 5 m.

So far terminals in *Cell DCH state* has been discussed. However, terminals in *Cell FACH* and *Cell PCH state* will be very useful in travel time estimations since the terminal performs cell updates in both of these states. Depending on the size configuration of URA, also terminals in *URA PCH state* might produce useful information. Terminals in these three states are characterised by having small amounts of data with low QoS demands to transfer [25]. If the URA is configured to be large, the information from URA updates can be used for the same purpose as RA or LA updates, e.g. as input for O-D matrix estimations or traffic flow measurements over large areas.

Another fundamental difference between UMTS and GSM is the physical layer implementation. The characteristics of the modulation and wide spectrum of UMTS make it more suitable for positioning [29]. These characteristics may also affect the possibility to estimate the speed of the terminal according to the reception properties of the signal. This type of speed estimation can be useful in estimating travel times; it will however depend on implementation of the technique in the cellular networks. Different solutions to do this are described in [30]-[32].

The physical layer implementation also calls for another crucial characteristic of UMTS compared to GSM, in general significantly smaller cells. A denser network of base stations makes the location accuracy better, both in terms of active and passive monitoring.

VI. POTENTIAL EFFECT AND BENEFIT

A drawback of current systems for estimating travel times from GSM networks is that they are not working well in urban environments. The challenge using this kind of system in an urban environment lies mainly in the large number of non-vehicle terminals and possible routes. Furthermore is the mean speed of vehicle terminals not much higher than non-vehicle

terminals, especially in the case of congestion. Complementing the measurements from the GSM network with a tailor-made system for the UMTS network might make it possible to use this technique for travel time estimations also in more challenging environments, e.g. the urban environment.

Apart from a larger usage area, information from the UMTS network will potentially give more reliable data with higher updating frequency. A higher updating frequency is crucial if the system is used for incident detection.

The measurement reports generated by UMTS terminals might be very useful if power level prediction is used for positioning and map matching. The possibility of polling measurement reports from UTRAN can be an important tool if the hybrid approach to traffic monitoring is used.

A simple example of how the information from a UMTS network can be utilized in travel time estimation is shown in Fig. 1. In a system with hard handover both route 1 (R1) and route 2 (R2) will be characterized by the handover sequence C1-C2-C3. In this example even with the use of TA values it will probably be difficult to distinguish between R1 and R2. Analysis of power level measurements of surrounding cells combined with a power level prediction map might give the possibility to distinguish the routes. In a system with soft handover R1 and R2 can be distinguished based on the handover sequence only. The handover sequence of R1 will be C1-C1/C2-C2/C3-C3, while the handover sequence for R2 will be C1-C1/C2-C2/C2/C4-C2/C3/C4-C3/C4-C3. In a denser road network this extra information might be decisive in order to determine the route of a terminal.

VII. CONCLUSIONS

The difference in RRM and physical layer implementation in UMTS compared to GSM can be useful in order to improve the quality of road traffic generation from cellular networks. Cell breathing is a potential problem in UMTS networks, but smaller cells, soft handover and flexible measurements have

Figure 1. Simple model of a cellular network with four cells and two routes.

the potential to increase the usage area and information quality. Tailor-made simulation models and algorithms for UMTS networks together with field tests will reveal the future possibilities of road traffic generation from cellular networks.

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