Investigation of the UMTS to GSM handover procedure

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Abstract- **UMTS is a third generation mobile communications system, currently being standardized and developed by many mobile technology manufacturers and operators. Unlike the second generation systems such as GSM, which provide voice and low speed data services, 3G promises to provide high speed data as well as multiple-data rate services, which is opening doors to many exciting multimedia applications. The initial deployment of UMTS is expected to be in cities, providing islands of coverage. Therefore, effective handover from UMTS to GSM is imperative for mobiles when they roam out of UMTS coverage. The aim of this paper is to present the results of system simulations which provide some insights into the conditions and parameters involved in inter-system handover from UMTS-FDD to GSM.**

I. INTRODUCTION

The demand for mobile communications worldwide has been dramatically increasing over the past decade. In particular, the Global System for Mobile communications (GSM) has enjoyed enormous success over the past decade, in particular in Europe and Asia-Pacific. In western Europe, GSM coverage exceeds 90% in some countries, while the mobile penetration levels can be higher than 60%. Second generation mobile networks, such as GSM, were designed primarily for narrowband voice and circuit switched data traffic. The requirement for expansion of cellular services to deal with high-speed mobile Internet, intranet, video and other data-oriented services, has promoted the inception of global third generation (3G) technologies. The most widely accepted 3G standard is the Universal Mobile Telecommunications System (UMTS), which is currently being specified by the 3rd Generation Partnership Project (3GPP). The underlying radio access technology for Frequency Division Duplex (FDD) operation is Wide-Band Code Division Multiple Access (WCDMA) often termed the UMTS-FDD mode. UMTS-FDD will deliver data rates of up to 2 Mbits/s indoors, and up to 384 kbits/s in the outdoor environment.

The initial deployment of UMTS is expected to be in city centers, where the density of the subscribers is high. This means that UMTS will initially provide islands of coverage, such as the one shown in Fig. 1. Since the UMTS islands of coverage will exist in a "sea" of GSM coverage, the effective inter-Radio Access Technology (RAT) handover between UMTS and GSM will be imperative to ensure continuity of service for dual mode UMTS/GSM mobiles. Furthermore, it is expected that UMTS coverage will not be perfect and coverage holes will exist even within the UMTS coverage islands, for example inside buildings, in garages, and in deep shadowed areas. This means that handover to GSM will be required even in those areas in order to avoid call dropping. Finally, handover between UMTS and GSM can also have a positive effect on capacity through the possibility of load sharing.

The aim of this paper is to study the procedure and the conditions for handover from UMTS to GSM. The paper presents the results of Motorola's JUPITER system simulation tool [1], which is used to analyze various measurement quantities that may be used to make a UMTS to GSM handover decision. The focus of the paper is on simulation of handover conditions for voice users, however the conclusions and the findings also apply to circuit switched data services. Packet switched services are not analyzed, as the packet service continuity in the areas of poor UMTS coverage is ensured by cell reselection rather than the handover procedures described in this paper.

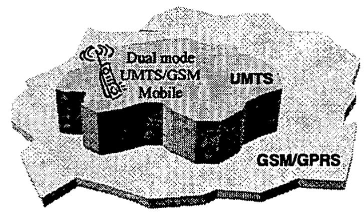

Fig. 1: Initial UMTS availability in the islands of coverage

II. UMTS TO GSM HANDOVER PROCEDURE

In order to avoid call dropping and poor quality of service, mobiles in active circuit switched calls that are leaving UMTS coverage need to be handed over to GSM. 3GPP standards have defined the necessary signaling and a range of parameters which may be used to perform inter-RAT handover from UMTS to GSM [2]. However, the decision on the conditions for inter-RAT handover and the optimization of the handover parameters are network and operator-dependent. The correct choice of handover conditions and parameters is essential, as it can greatly impact the system performance in terms of call dropping rate, maintenance of call quality, handover success and avoidance of unnecessary handovers.

The inter-RAT handover procedure performed by the network can be divided into the following main steps:

- Setup of inter-RAT measurements
- Event-triggered inter-RAT measurement reporting
- Inter-RAT handover detection
- Inter-RAT handover execution

As part of the measurements setup procedure, the first decision that needs to be made by the UMTS network (UTRAN) is which mobiles in active UMTS calls need to be instructed to start performing GSM measurements. These mobiles would then be provided the details of the GSM neighbor cells to be measured, measurement quantities and reporting conditions. Measurement reporting in UMTS can be event triggered, which means that UTRAN can instruct mobiles to send measurement reports on GSM neighbors when a particular inter-RAT event occurs. From a range of events defined by standards specifications, the following inter-RAT reporting event is investigated in this paper [2]:

- Event 3a: The estimated quality of the currently used UTRAN frequency is below a certain threshold and the estimated quality of the other system is above a certain threshold.

The following measurement quantities may be used to estimate the quality of a UTRAN frequency [3]:

- Received signal code power (RSCP): the power-per-chip received on a common pilot channel in UMTS-FDD.
- Received signal strength indication (RSSI): the received power within the system bandwidth. Note that the RSSI measurement is mainly used for inter-frequency UMTS cell measurements, and will thus not be analyzed in this paper.
- Ec/No: The chip-to-noise energy ratio for a UMTS-FDD common pilot channel. This value is identical to RSCP/RSSI. Note that in some publications, the Ec/No measurement quantity is referred to as Ec/Io.

The measurement quantity for GSM neighbor cells is the RXLEV, which is defined as the average of the received signal level measurement samples in dBm taken on the measured channel [7]. Note that in some literature, the RXLEV is referred to as the GSM Carrier RSSI.

If the inter-RAT reporting conditions are satisfied during the averaging period, the mobile sends a GSM measurement report to the network, which may then be used to evaluate the inter-RAT handover conditions. If necessary, the network then executes handover by sending the HANDOVER FROM UTRAN COMMAND to the mobile, which contains details of the target GSM cell [2].

The main focus of this paper is on the measurements part of the inter-RAT handover procedure, which involves the decision when to instruct mobiles to start measuring and when to instruct them to start reporting on GSM cells. The methods for the mobiles to perform inter-RAT measurements are discussed in more detail in the following section.

A. *Performing Inter-RAT measurements*

Performing inter-RAT measurements on GSM is somewhat problematic for mobiles in active UMTS calls, due to the fact that transmission and reception in UMTS-FDD is continuous. One way to overcome this problem is by implementing a dual receiver multi-RAT mobile, which can simultaneously access both GSM and UMTS. The advantage of this approach is that a dual receiver mobile can quickly synchronize with GSM cells and perform GSM measurements while in an active UMTS call. However, the disadvantage is the additional cost involved in implementing two receiver chains in the mobile. Because of this, 3GPP standards have defined the compressed mode mechanism, which enables mobiles with a single receiver chain to perform inter-RAT measurements [4]. However, it is worth noting that even dual receiver mobiles always require uplink compressed mode for measurements on GSM 1800, due to the proximity of this band to the UTRA-FDD uplink band.

Compressed mode enables data to be transmitted in a shorter amount of time, which leaves idle periods that can be used to perform measurements on other frequencies, as shown in Fig. 2. 3GPP standards define three transmission time reduction methods: lowering the data rate from higher layers, increasing the data rate by changing the spreading factor, and reducing symbol rate by puncturing at the physical layer multiplexing chain [4]. The use of compressed mode for inter-RAT measurements can result in long synchronization times, e.g. a single receiver mobile in an active UMTS call may require more than 5s to synchronize to one GSM cell under Gaussian channel conditions [3]. However, the actual synchronization time is dependent on the choice of compressed mode parameters, so optimization of these is essential for every network manufacturer and operator.

The use of compressed mode also has a detrimental impact on the link performance, as detailed in [5]. Link performance is most impacted at the cell edge, i.e. when the mobile is transmitting at maximum power and the required Signal-to-Noise Ratio (Eb/No) is increased. UMTS system capacity may also be impacted by the use of compressed mode [6]. This problem is particularly difficult on the downlink as power is a limited resource on the downlink, and compressed frames have increased power requirements. This issue is compounded by asymmetric data traffic, where the volume of downlink data traffic is many times greater than that of uplink traffic.

Because of these problems involved with the use of compressed mode, the network needs to optimize the amount of GSM measurements performed by the mobile, while ensuring continuity of service at the edge of UMTS coverage.

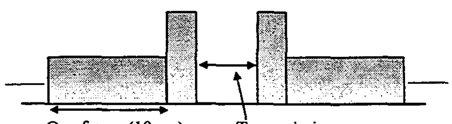

Fig. 2: Compressed mode transmission

III. SIMULATION APPROACH

The evaluation of the UMTS to GSM handover procedure presented in this paper is based on Motorola's "JUPITER" system simulation tool. JUPITER simulator is normally used as a network planning tool, to estimate capacity and range of UMTS cells for a wide range of input conditions including service mix, loading, base site configurations, propagation channel models and mobile speeds. JUPITER produces two types of output files: statistical data at the mobile and the site, and image data indicating overall system state. A detailed description of JUPITER's inputs, outputs and operation is given in previous Motorola's publications [1].

To evaluate the UMTS to GSM handover procedure, an example system has been chosen for JUPITER simulation, as shown in Fig. 3. The simulation space contains 19 tri-sectored

UMTS sites providing an island of UMTS coverage. The GSM system is assumed to provide continuous coverage, and UMTS and GSM cells are assumed to be co-located. There are 1000 mobiles in the simulation space, which are randomly distributed and are represented as black dots in Fig. 3. The rest of the assumptions used in system simulations are listed in Table 1.

Chip rate	3.84 Mcps
Frequency of system	2 GHz
Cell radius	1000m
Path loss model	Urban: 32.1 + 35.2 * log10 (d/m); shadowing variance 8 dB
Voice activity factor	66%
Service mix	100% voice users at 12.2kbps
Soft-handover window	5 dB
Noise figure	Uplink: 5 dB; Downlink: 9 dB
Site topology	tri-sectored
Node B antenna gain	13 dBi (incl. cable loss)
Transmit power	43 dBm
Maximum transmit power per speech user at node B	1 W
Common pilot transmit power	2 W
UE transmit power	21 dBm
UE gain (incl. body loss)	-3 dBi
Mobile speed	3 km/h
Minimum mobile finger locking threshold (Ec/No)	-18.75 dB
Performance targets	Uplink and Downlink target FER is 1%, outage point is 3%
Soft Handover Algorithm	DL: Equal gain combining UL: Selection combining
Diversity schemes	DL: Space Time Transmit Diversity with 2 Tx antennas UL: Maximal ratio combining with 2 Rx antennas

Table 1: Simulation assumptions

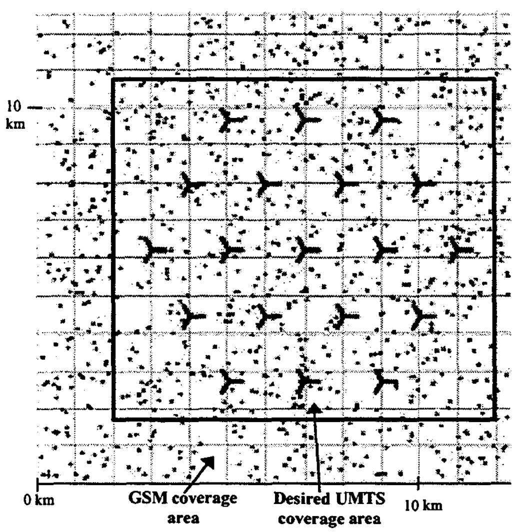

Fig. 3: UMTS Node B layout and the mobile distribution.

IV. SIMULATION RESULTS

The aim of this section is to provide some insights into how the network could optimize the inter-RAT measurement procedure performed by the mobile in order to ensure effective UMTS to GSM handover.

As part of the measurements procedures, the network firstly needs to decide when to instruct mobiles to start performing GSM measurements. A simple approach to this is to define an area of border UMTS coverage and to instruct all active-mode mobiles in this area to perform GSM measurements. A shown in Fig. 3, the simulated island of UMTS coverage consists of 19 base station sites. The border cell approach would mean marking the outer ring of base station sites as border cells, and initiating inter-RAT handover measurements for all mobiles served by these cells. Whilst this approach is suitable for most scenarios, note that coverage will not be perfect even in the areas of contiguous UMTS coverage and coverage holes can exist inside buildings due to in-building penetration losses and also in the areas affected by deep shadowing. In these areas, handover to GSM will be required in order to avoid call dropping. Because of this, it could be argued that it is necessary to instruct mobiles to perform measurements on GSM over the entire area of UMTS coverage. However, this approach could also be problematic, since a large number of multi-RAT mobiles will require compressed mode to perform GSM measurements. As described in section II, the use of compressed mode has a detrimental impact on system capacity and link performance. The decision on when to initiate GSM measurements therefore needs to take into account mobile's measurement capabilities and be performed as a trade-off between ensuring that effective handover to GSM can be performed in areas of poor UMTS coverage, whilst also minimizing the impact of compressed mode on overall system performance.

The second decision that needs to be made by the network is when to instruct mobiles to start reporting on GSM and which measurement reporting quantities to use. As described in section II, event-triggered measurement reporting may be used in UMTS, and the event chosen in this paper to instigate GSM measurement reporting is event 3a: "The estimated quality of the currently used UTRAN frequency is below a certain threshold and the estimated quality of the other system is above a certain threshold". The estimated quality of the currently used UTRAN frequency may be based either on the pilot channel chip-to-noise energy ratio (Ec/No), or the power per chip on the pilot channel (RSCP). An indication of suitability of using Ec/No to determine UMTS coverage may be obtained from the results in Fig. 4. The mobiles in outage, i.e. those that do not satisfy the Frame Erasure Rate (FER) performance targets are shown with a red circle in Fig. 4. It can be observed that in the border of UMTS coverage, the Ec/No falls off slowly as the mobile moves away from the UMTS cell site. This results in some mobiles meeting the FER targets despite being several kilometers away from the nearest base station. Fig. 4 thus shows that the range of UMTS cells is extended in the border regions of coverage.

A more detailed investigation of using the Ec/No as the measurement quantity in the inter-RAT handover procedure is shown in Fig. 5. This figure shows the cumulative distribution of the number of users which satisfy the Ec/No reporting threshold at a certain distance from cell. It has also been assumed that users outside the desired UMTS coverage square shown in

Fig. 3 need to be instructed to start sending GSM measurement reports. From Fig. 5 it can be observed that for voice users and cells at the edge of UMTS coverage, the Ec/No reporting threshold needs to be set at -12.5 dB, to ensure that the mobiles do report on GSM outside the desired UMTS coverage area.

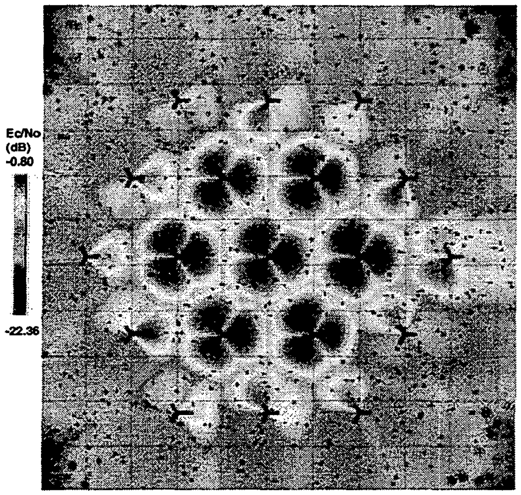

Fig. 4: JUPITER output showing the Ec/No mesh.

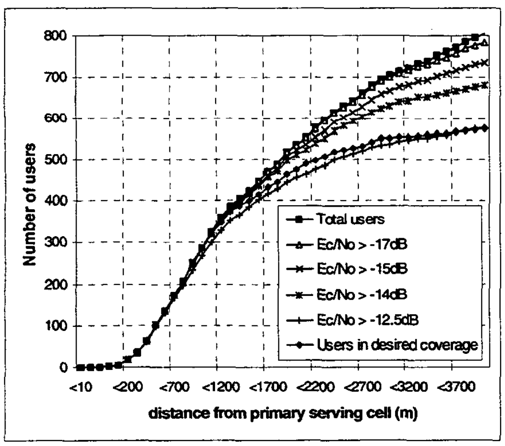

Fig. 5: Users satisfying the Ec/No reporting threshold

When selecting the Ec/No reporting threshold, we also need to ensure that the mobiles aren't already in outage before they start sending GSM measurement reports. The simulation results in Fig. 6 show the numbers of mobiles in outage for a cumulative distribution of Ec/No's. The users in outage have been separated into those in uplink outage, downlink outage and those who simultaneously suffer both uplink and downlink outage, i.e. they have not met the FER targets on uplink or downlink. The results in Fig. 6 show that none of the mobiles in the simulation space are in outage for the values of Ec/No better than the reporting threshold of -12.5 dB. This means that the choice of Ec/No reporting threshold of –12.5dB is a correct one for voice service, in terms of ensuring that reporting on GSM is done before outage occurs. However, the difficulty with choosing such a high value of Ec/No as the reporting threshold is that a large number of mobiles will be instructed to send measurement reports on GSM, which will increase the overall signaling load on the system, and also unnecessary handovers to GSM may be initiated. Because of this it is necessary to investigate whether the pilot channel RSCP is a better choice of quantity to trigger inter-RAT measurement reporting in border regions of UMTS coverage.

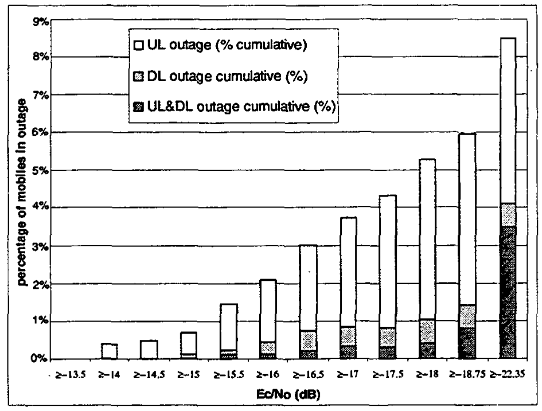

Fig. 6: Percentage of mobiles in outage for a cumulative distribution of Ec/No's

Fig. 7 shows the comparison of the change in the pilot channel RSCP and Ec/No measurement quantities with the distance from the primary serving cell. It can be observed that there is a much stronger correlation between the rate of change in the RSCP with the distance from cell, than for the Ec/No. Additionally, there is a great variation in the Ec/No at small distances between the mobile and the cell site. For example, at the distance of 1.1 km from the cell site, the Ec/No ranges between –7dB and –15dB. The variation in the RSCP at the same distance from cell is much smaller, that ranges between –96dBm and –99dBm. This means that if, for example, we wanted to ensure that mobiles start sending GSM measurement reports at distances greater than 1.1 km from the serving cell, a suitable value of RSCP reporting threshold would be –99 dBm.

The above analysis therefore indicates that using the RSCP measurement quantity to trigger inter-RAT reporting can be more robust than the use of Ec/No in the border regions of UMTS coverage, due to the strong correlation between the rate of change in RSCP and the distance from cell. This can be explained by the fact that RSCP is an absolute measurement of the signal level, whereas Ec/No is a ratio of the wanted signal to signal plus interference. In scenarios where fast handover to GSM is essential, such as leaving an area of coverage or entering very deep fading, both the wanted and interfering signals drop together and consequently the change in Ec/No is quite small.

However, a possible issue with using the RSCP as a measurement quantity for the inter-RAT handover decisions is the low required measurement accuracy for this quantity. 3GPP standards specify that the mobile needs to be able to perform intra-frequency RSCP measurements with accuracy between ±6dB and ±11dB depending on channel conditions [3]. On the other hand, mobiles are required to measure the Ec/No with a much greater accuracy. This ranges between ± 1.5dB and ± 3 dB, depending on the value of the measured Ec/No and the channel conditions [3]. It can therefore be concluded that although RSCP gives a better indication of coverage than the Ec/No, its low required measurement accuracy can cause issues with using this quantity for the inter-RAT handover decision.

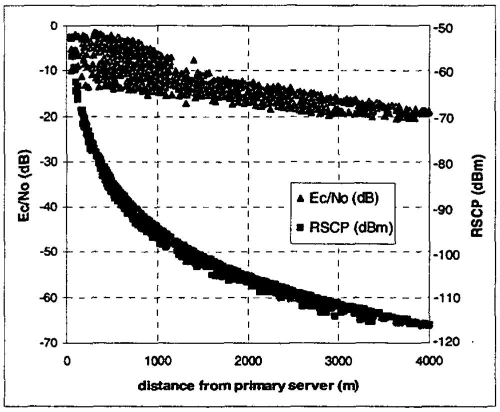

Fig. 7: Comparison of rate of change of Ec/No and RSCP with the distance from primary serving cell

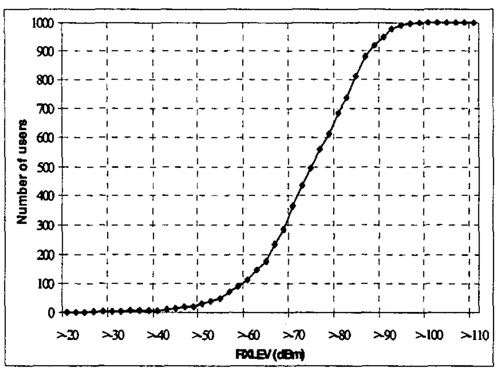

Fig. 8: Mobiles satisfying the GSM RXLEV reporting threshold

Another condition for the mobile to start sending measurement reports on GSM, based on event-driven processing described in section II, is that the estimated quality of the other system is above a certain threshold. As described in section II, the GSM reporting quantity is the RXLEV. Since the simulations assume continuous GSM coverage, the GSM RXLEV threshold should be chosen such to enable most users which are at the edge of UMTS coverage to effectively handover to GSM. Fig. 8 shows the cumulative distribution of users satisfying GSM RXLEV thresholds. For example, if the RXLEV reporting threshold was chosen to be -90 dBm, 95% of the mobiles in the simulation space would satisfy this threshold and would be able to effectively send measurement reports on GSM.

CONCLUSIONS

The procedure and the conditions for handover from UMTS to GSM were studied in this paper. The presented analysis was focused on the inter-RAT measurement procedures, which are used to trigger handovers from UMTS to GSM. The conditions for initiation of inter-RAT measurements were studied, taking into account different capabilities of the mobiles. It has been shown that there are issues with using single receiver mobiles requiring compressed mode for inter-RAT measurements, in terms of the delays in synchronization with GSM cells, as well as the detrimental impact of compressed mode on the link performance and system capacity. Taking these factors into account, the analysis has shown that the decision on when to initiate inter-RAT measurements needs to be a trade-off between ensuring that effective handover to GSM can be performed in the areas of poor UMTS coverage, whilst also minimizing the impact of compressed mode on the overall system performance.

The paper also presented results of system simulations, which provide insights into the optimal choice of measurement reporting quantities and conditions for event-triggered inter-RAT reporting. Suitable values of Ec/No, RSCP and GSM RXLEV measurement reporting thresholds were obtained from system simulations. Finally, it has also been found that the RSCP measurement quantity gives a better indication of coverage than the Ec/No, but its low required measurement accuracy can cause issues with using this quantity to make the inter-RAT handover decision.

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