GSM PROCEDURES IN AN INTEGRATED TERRESTRIAL/SATELLITE MOBILE SYSTEM

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ABSTRACT

In this work some of the procedures of the GSM standard are analyzed for a possible integration of a satellite component. The integration scenario influences the degree of re-utilization of the GSM procedures. A fundamental assumption is that modifications, if required, should be confined to the mobile station or to the ground infrastructure of the satellite sub-system.

1. INTRODUCTION

The level of integration between the GSM system and a possible satellite component influences the amount of GSM protocols and entities that can be re-used in the satellite sub-system [1-5].

A classification of the integrated system based on management criteria can include two classes:

- the satellite sub-system implements one or several autonomous networks that are logically and functionally equivalent to PLMNs, added and overlaid to the existing GSM PLMNs: each satellite operator has its own HLR;

- the spot beams are managed by operators that own a GSM PLMN. The GSM HLRs manage also spot footprints, logically and functionally considered as macrocells of that PLMN.

The use of NGSO satellite systems is foreseen for future mobile personal communications. In NGSO systems [6] the motion of the spot footprints with respect to the earth surface leads to additional functionalities that have to be implemented in the satellite sub-system:

a) network access. In cellular networks, before and during a communication, a mobile terminal establishes an association with the base station which permits the best communication quality. In a NGSO system a double association is needed:

- a first level association connects the mobile terminal to a particular satellite of the constellation. Various criteria can be adopted to choose a specific satellite among those presently in view from the terminal.

- a second level association joins the satellite to a particular FES. This association could be employed to define the concept of location area for a NGSO system: a location area could be connected to the area controlled, at the moment, by a FES. Because of the moving of the satellites, these associations cannot be considered fixed, even if the mobile terminal does not move;

b) routing. In a cellular network, a call towards a mobile user is routed to the location area where the terminal is located at the moment. In a NGSO system the routing might be achieved also by means of Inter-Satellite Links (ISLs). Several proposal are under study presently. In any case, ISLs do not have direct correspondence with the functionalities of a cellular network;

c) handovers. In NGSO system, the activation of a handover procedure is mainly due to the mobility of the constellation. Two handover events can be distinguished:

- handover between spot beam, when the terminal is coming out a spot footprint;

- handover between FESs, when the active FES is going out the visibility of the satellite.

In LEO systems, which seem preferred for the implementation of satellite personal communication networks, the mobility of the constellation is so fast that the motion of the mobile terminal is negligible. In these conditions, the handover become predictable, can be scheduled and can be carried out in a simplified way.

In an integrated system, handover could be foreseen between the two sub-systems:

- handover from a spot beam to a cell, useful to free satellite channels;

- handover from a cell to a spot beam, useful when a mobile terminal is leaving the cellular coverage.

It is evident from the preceding items that the GSM procedures could supply a sub-set of the functionalities that have to be foreseen for a NGSO system.

The following assumptions seem reasonable working hypotheses:

- solutions for the integrated system requiring any modification to the existing protocols of the terrestrial network are not acceptable. Modifications, if required, should be confined to the dual-mode MS and/or to the ground infrastructure of the satellite sub-system;

- satellite channels are assigned to communication traffic only if no GSM radio channel is available.

This work considers typical procedures of a cellular network. The procedures considered will be:

i)   cell selection and reselection
ii)   location of mobiles
iii)   synchronization
iv)   call set-up

For each of the procedures considered, the protocols used by the GSM system will be reviewed and then their possible extension (and related problems) to an integrated GSM-satellite system will be discussed.

2. SELECTION AND RESELECTION

2.1 Selection and reselection in GSM

An MS is in idle mode state when it is not actively processing a call. When the MS is in this state, it performs the activities of cell selection and reselection. The selection procedure is performed when the MS has no information of the cellular environment, e.g. after the switch-on or after the re-entering of the terminal into the system radio coverage. The reselection procedure aims to select a new cell, as a consequence of the movements of the MS, that permits a better quality of the received signal.

The MS accesses to the GSM services in the selected cell: in the set-up of a mobile terminating call, the MS replies to the paging signal sent by the BS in the selected cell, whose PCH is continuously decoded; in the set-up of a mobile originating call, the MS sends the access bursts on the RACH of the selected cell.

To perform the cell choice, the MS has to evaluate the average signal power received on the BCCH frequency of the presently selected cell and of the adjacent ones, listed on the BCCH channel.

At the beginning of the selection procedure, the average level of the received signal on each one of the 124 RF carriers of the GSM system is computed. Considering all the RF channels starting from that with the highest average power, the MS selects the first BCCH carrier that meets *suitable cell* conditions. If a suitable cell has not been selected after the examination of 30 RF channels, the MS selects a new PLMN.

A MS in idle mode, after having selected a cell, performs the following functions:

- it continues monitoring all the BCCH carriers of the allocation list, transmitted on the BCCH of the selected cell;
- for each of these carriers it evaluates the average received power;
- it creates a list of the 6 carriers (excluding the one of the selected cell) with the highest average power;
- for each of these carriers it determines if a better quality signal can be achieved and, if necessary, performs a reselection procedure.

Before reselecting the new cell, the MS decodes the BCCH data, verifies that the reselection parameters are not changed and, if they are, controls that the

reselection criterion is still satisfied. In this case the MS selects the new cell and, if necessary, starts a location updating. If the reselection conditions are not met for that cell, the MS repeats the procedure for the cell having quality parameters immediately smaller. If within 10 seconds no suitable cell is selected, a new selection procedure is performed for a different PLMN, chosen according to a PLMN selection procedure. Reselection failure occurs when the MS is moving outside the coverage area of the present PLMN.

2.2 Selection and reselection in an integrated system

In all the satellite architectures the spot beams can be considered as macrocells and, in an integrated system, the MS can extend the selection procedure considering the satellite link.

The procedures must account for the different role [7] of the terrestrial and satellite resources, assigned according to the following criterion: the terminal should try to use the terrestrial cellular channels and only if they are not available, for whatever reason, the access to the satellite link will be tried. The underlying hypothesis is that the satellite resources should be kept free as much as possible.

In an integrated system the cell selection should be first performed in the GSM network and only after its failure it should be carried out in the satellite segment.

If the MS has initially selected a GSM cell, it performs the reselection procedure as described above. Otherwise, if the MS has initially selected a satellite beam, the reselection is performed among other beams, that is a list of BCCH carriers related to the adjacent beams must be broadcast by each beam. As a drawback, if a MS has selected a spot it continues to use it even if either terrestrial resources become available or it enters the cellular coverage. In our hypothesis, however, the satellite resources should be used only when the GSM ones are unavailable. To achieve this purpose it is necessary that, when the MS has initially selected a spot beam, it periodically checks also terrestrial resources, that is:

- it carries out the reselection with other beams;
- at regular intervals it suspends this activity and performs a selection procedure on the GSM band.

3. LOCATION OF THE MSs

3.1 Location updating of MSs in GSM

Location registration and location updating is the set of procedures by which a PLMN determines or updates the MS position within the network. These procedures are essential to the network for the routing of a mobile

terminating call. The area used for the location of the MS is called *location area* (LA).

In GSM a LA is composed by one or more BS areas and is identified in a PLMN by a LA identification, which is a parameter transmitted on the BCCH of each cell. In each VLR the information about all the MSs present in its LA are stored. Within a LA the MS can move without updating its position registration in the VLR of that LA. The MS initiates the location updating procedure when it detects to be entered in a new LA, i.e. when on the current BCCH it receives a *location area* identification different from the one currently stored.

After having requested a SDCCH channel, the MS starts the procedure sending on it a *location updating request* containing the indication of the updating type. After receiving this signal, the network performs different operations depending on the fact that the new and the current LA are or are not controlled by the same VLR (in the latter case the HLR is also involved).

The MS is informed of the updating by the message *location updating accept* and stores the new *location area identification*, resetting the counter for the periodic updating. Now the MS can perform the normal function of listening to the new paging channel.

3.2 Location updating of MSs in an integrated system

In GSM the location updating procedure is activated when, after a cell selection or reselection, the target cell belongs to a different LA. Therefore, the location of a MS is strictly related to the cellular areas identified by the BSs coverage.

For GEO systems, a satellite location area could be constituted by one or more spot footprints and the same GSM concepts, related to the location updating, seem largely re-usable. This consequence derives from the fact that in GEO the radio coverage provided by satellite footprints is static, as it is for the coverage assured by BSs in cellular networks.

In a NGSO system, instead, the GSM procedure of location and location updating is not suitable in most of the cases, because of the dynamics of the constellation: both the FES and the mobile terminal remain in a spot beam for a short time.

In an integrated system, the concept of MS Location Area and the area covered by a BS (or a set of BSs) could be more loosely related than in GSM.

A first approach to MS locating in the satellite environment is to identify the LA of the MS with the area covered by one spot beam. In this case, whenever a MS reselects a new beam it must also perform a location updating. However, because of satellite motion and reduced visibility time, the required signaling overhead could be excessive [8]. The

frequency of the location updating could be reduced by choosing the whole satellite footprint as the LA associated to a MS: the disadvantage is that when a MS needs to be contacted, all the satellite coverage zone needs to be paged, thus reducing the paging efficiency. It must be noted that location updating is no longer due to the MS mobility that can be neglected with respect to satellite motion.

A second approach, relies on the ability of each MS to detect its position. In this case the MS stores its position in terms of terrestrial coordinates (latitude and longitude). When the measured position is far from the stored one more than a given uncertainty radius R_u, then a location updating is performed. In this case, the procedure of beam selection due to satellite motion becomes independent from that of location updating.

Location Area information are used by the network in order to contact the MS in a mobile terminating call. In GSM LA coincides with the *paging area* and the LA identifier can be considered a routing information. This also holds for the first approach described above for the integrated system. The second approach needs a necessary mapping from terrestrial coordinates to satellite resources.

4. SYNCHRONIZATION

4.1 Synchronization in GSM

Synchronization is the procedure that allows the MS to properly position its transmission bursts in the TDMA frame specified by the GSM system. On the GSM RF link it is possible to distinguish three synchronization levels:

1) the uplink and downlink frames are cyclically numbered, module 26x51x2048; the various control and traffic channels are defined and communicated by the BS to the MSs with reference to the frame number. So it is very important for the MSs to decode the current frame number, sent on the BCCH carrier every ten frames;

2) the frame is divided into 8 slots; each MS must know the current timeslot both when it is in idle mode and when it is communicating with the network. In idle mode, this knowledge is necessary for the MS to ascertain the instants at which it may send an access burst and to determine the time intervals for listening to the paging channel. During a call, the mobile has to send and receive the traffic bursts within the assigned timeslots;

3) while a conversation is in progress, the bursts sent on the uplink have to arrive to the BS aligned with the initial instant of the slot assigned to that communication, so that they do not overlap with adjacent slots. In the GSM system, the MS places its packets on the basis of the information supplied by

the BS with which it is communicating. The BS sends to each MS that has a call in progress the *timing advance* (TA) parameter, whose value depends on the estimated delay on the link BS-MS-BS. The MS anticipates its transmissions by this value, in order to compensate this delay. This process is called *adaptive frame alignment*.

Before describing the assignment of the TA, consider the procedure of the request of a dedicated channel from the mobile. Such request can be initiated by a MS following a paging message received from the BS. The network initiates the paging procedure sending a *paging request* on the paging sub-channel. After receiving a *paging request*, the MS initiates the *immediate assignment* procedure (described below) and, on the assigned channel, the MS sends the message *paging response*.

To access a BS the MS sends the *random access* burst during the RACH timeslot of the frame. The RACH is one of the Common Control Channels (CCCH). After receiving this message, the network assigns, if possible, a SDCCH to the MS sending the message *immediate assignment* on the CCCH. The message contains the frame number of the frame where the *channel request* was received, the indication of the assigned channel, the initial *timing advance* and optionally the indication of the *starting time*. If the last parameter is present, the MS must wait for the indicated frame before starting its transmissions on the assigned channel. After receiving the *immediate assignment*, the MS tunes on the indicated SDCCH and the associated SACCH channels.

In the GSM the BS can determine the initial value of the *timing advance* evaluating the delay of the received access burst with respect to the beginning of the slot: this delay corresponds to the total round-trip delay. The frame transmitted by the BS is received by the MS with a propagation delay Tbm. In the access phase the MS does not take into account this delay and synchronizes with the received frame, sending the random access burst at the beginning of a RACH slot. This signal arrives at the BS delayed by Tmb. The random access burst is sufficiently short, so that, even if delayed by Tbm+Tmb, it remains within the allowed slot (it does not overlap with the following slot). The GSM has an access burst of 88 bits (0.325 ms) and, therefore, a guard time of 68.25 bits (0.252 ms). Consequently Tbm+Tmb=0.252 ms. Assuming the two delays equal to Tr, we have that Tr_{max}=0.126 ms, which corresponds to a maximum BS-MS distance of about 37.7 km. The GSM system allows cell with maximum radius of 35 km.

The maximum allowed value for the *timing advance* is 63 bits. The BS continues monitoring the delay of the received signal and, if it detects a variation greater than one bit period with respect to the current *timing advance*, the parameter TA is increased or decreased by 1 and signaled to the MS. When the MS receives a new TA on the SACCH, it synchronizes accordingly its transmission, starting from the next SACCH message.

4.2 Synchronization on the satellite link

A notably different solution must be used in the satellite network, due to the long propagation delay and the quite large delay variation depending on the position of the MS within the spot beam.

After receiving the access burst from the MS, the FES-BS must compute the delay of the received message. If we wish to apply TDMA to access the satellite, some modifications to the GSM parameters must be introduced.

Two aspect of the satellite links must be taken into account: the higher propagation delay and the larger size of the satellite cells. In the satellite environment the round trip delay results to be greater than the time slot, that is a RA burst not only will not reach the FES-BS within a time slot, but it will be received in a different frame number. Moreover, the difference between the minimum single hop time delay, t_m (when the MS is at the minimum distance d_m from the satellite) and the maximum single hop time delay, t_M (when the MS is at the maximum distance d_M from the satellite) is still greater that a slot time. The propagation delay from MS to FES-BS can be computed if the RACH slot time has a suitable length. Let $D=t_m - t_M$. The difference between the RA bursts received by the BS and transmitted by two MSs at the distance d_m and d_M, respectively, is always less than 2D. For this reason, RACH time slots must have, at least, a length of 2D. The cell size in GSM permits a RACH slot time equal to that of all the other logical channels: in a satellite environment this does not hold. Therefore, a solution to this problem can be achieved if, in each spot, the uplink of a given carrier is reserved to the RACH slots. As a drawback, no traffic channels can be transmitted on the downlink in correspondence with the RACH slot: the system should fill these slots with dummy bursts to maintain constant the power of the transmitted signal. Another possibility would be to assign an *access carrier*, only used in uplink, to RACH slots.

The high propagation delay between MS and BSs in the satellite environment causes also problems in the numbering of the frames. In fact in the GSM system, at the BS the uplink and downlink frames are aligned (same frame number), with the downlink frames advanced by 3 timeslots with respect to the uplink frames; at the MS side the uplink frame is delayed by (3 timeslots)-(*timing advance*) with respect to the received frames, but frame number does not change.

On the satellite link, this coincidence of frame numbers is not possible, since the round trip delay, also for LEO satellites, is greater than a frame period. Then two possibilities can be taken into account:

1) the frame numbers coincides at the BS side: at the MS side the current frame number on the downlink is less than the current frame number on the uplink;

2) the downlink and uplink frame numbers coincide for an MS at the maximum distance from the satellite. The actual staggering depends on the position of the terminal within the spot and must be communicated by the BS to the MS with the *immediate assignment* message.

Another aspect to be considered is the adaptive frame alignment on the satellite link. In the GSM an adaptive correction of the synchronization during a call is needed because of the MS roaming. In a NGSO satellite system the adaptive correction of the synchronization has also to account for the motion of the active satellite. Further studies are necessary to evaluate whether the GSM synchronization correction can cope with the fast satellite motion.

5. CALL SET-UP

5.1 Call set-up in GSM

A user of a fixed network (PSTN or ISDN) which wants to call a mobile, dials its MSISDN number. The fixed network recognizes the number belonging to a mobile user. The MSISDN number is associated to the IMSI according to national numbering criteria. The IMSI allows to know the HLR where the mobile customer is registered. Therefore the fixed network asks the HLR to obtain the MSRN, which allows the call to be routed to the MSC where the MS is located. The HLR request occurs through a gateway MSC, belonging to the called customer PLMN. This MSC sends the message *send routing information* to the HLR, which answers with the *routing information acknowledge*, containing the MSRN. Now the call can be routed to the terminal MSC, generally through PSTN networks. This MSC sends the *send information request, incoming call set-up* to its VLR. If the VLR has all the necessary information, it will reply with the *information acknowledge, incoming call set-up*, containing the IMSI and the location area indication of the called MS. Otherwise the VLR sends a *call data request* to the HLR, which then communicates the required data about the mobile user. Once defined the mobile user location area, the MSC spreads a search message, *paging*, through all the BSs belonging to that location area, using the IMSI. Before answering, the addressed MS has to establish a point-to-point connection with the selected BS: it sends the message *channel request* on the RACH, which is also used by the BS to calculate the distance from the mobile. The BS replies with the *immediate assignment* on the AGCH, containing the necessary information to assign a SDCCH: frequency, timeslot, sub-channel number, initial timing advance. The following control signals are transmitted on the SDCCH. The successive message *paging response*, sent by the MS, also establishes the ARQ mechanism, used during the call for some control signals. In the *paging response* the IMSI is indicated too. Optionally, MS and BS exchange themselves the messages related to the *authentication* and *cipher mode* procedures. At this point, the BS sends the effective *set-up* message. It may contain the calling user number, so that it is shown to the called user: this is one of the GSM supplementary services which a customer can subscribe, which needs the exchange of a further pair of signals between BS and MSC. The MS replies to the *set-up* with a *call confirmation* that is passed to the MSC. The MSC, knowing the required traffic channel type, communicates the *assignment request* to the BS. After having examined the availability of the RF resources, the BS sends the *assignment command* to the MS and switches to a traffic channel, indicated through the frequency and the timeslot number. The mobile disconnects the SDCCH and tunes to the TCH. Any other control signal will be exchanged on the FACCH. On this channel the MS communicates the *assignment complete*, which is passed to the MSC so that it releases the control channel. The terminal warns user about the arriving call and notifies the BS, with the message *alert*. When the call is accepted by the user, the MS communicates it to the BS with the message *connect*. As a response it receives a *connect acknowledge*. At this point, the message exchange between users may start. When the conversation ends, the messages *disconnect*, *release* and *channel release* are exchanged between BS and MSC and the *clear* commands are exchanged between other system entities.

In a mobile originated call, the mobile user selects the number to be called. The MS sends a *channel request* on the RACH and receives the message *immediate assignment* on the AGCH, with which a SDCCH is assigned. Now a *service request*, containing the IMSI, is sent by the mobile, this message also establishes the ARQ used for some control messages. After the optional procedures related to the *authentication* and *cipher mode*, the MS sends the effective *set-up* message, containing, in particular, the called number; this message is routed by the BS to its MSC. The MSC transmits the *call proceeding* and then asks information to its VLR, with the message *send information request outgoing call set-up*, using the IMSI. After interrogating the HLR of the calling MS, with a *call data request*, the VLR checks the customer data and communicates the MSISDN number to the MSC with the message *send information acknowledge*. Now the MSC sends the *assignment request* command to the BS, that, after its reception, communicates an *assignment command* to the MS. At this point, the terminal switches to the assigned TCH and transmits the *assignment complete* to the BS on the FACCH,

which is passed to the MSC. The MSC sends to the MS the *alert* and, when the called user accepts the communication, the *connect* command. The mobile terminal replies with the *connect acknowledge*.

At the end of the conversation the exchange of the messages *disconnect*, *release* and *channel release* occurs between MS and BS. Other *clear* signals are exchanged at the network side.

The procedure for a mobile-to-mobile call may be obtained from the ones previously described.

5.2 Call set-up on the satellite link

In principle, the GSM set-up procedure could be applied in the satellite sub-system. The aspect that must be carefully evaluated is related to the propagation delay on the satellite link. This delay has to be compatible with the GSM "time windows" on the RF link, that is the time interval between sending a message and receiving the reply must satisfy the GSM recommendations.

In the area covered by both the GSM and the satellite footprint, there are more than one possibility to contact the MS: this feature can be exploited by the network to solve traffic congestion problems that can occasionally arise. The traffic management criterion which is considered here is that the terrestrial resources should be used whenever possible. The ability of routing a call on different segments depends on the direction of the call, incoming or outgoing.

We can distinguish two cases, according to the segment presently selected by the MS.

1) the MS has selected a GSM cell. Therefore, it is registered in a terrestrial VLR and it is listening to a terrestrial PCH. If a traffic overload occurs in the selected cell, a satellite resource could be available.

In case of an incoming call, the routing through the satellite network involves some modifications to either the GSM architecture or the present integration scenario: in fact, the *assignment failure*, is managed by a GSM MSC and this entity does not foresee an attempt of set-up in a different segment; otherwise, the MS could be contacted through the satellite segment if it is registered also into a satellite VLR (the MS should perform two location updating) and listens also to a satellite PCH. The procedure for implementing this set-up is much more complex than the GSM one.

In case of mobile originated call, a GSM call set-up failure can be rerouted towards the satellite segment by forcing a location updating in the satellite environment and then trying a satellite call set-up (the user should be noticed of this choice).

2) the MS has selected a spot beam. As in the previously described case, if the set-up is attempted towards the MS and the spot beam is overload, there are no possibilities to reroute the call through the GSM network. In case of outgoing call, location updating into GSM can be performed and an attempt through the terrestrial resources can be tried.

6. CONCLUSIONS

In this work some of the GSM procedures have been described and their possible utilization in a satellite integrated system discussed. LEO satellites have been assumed as target system. Taking into account a possible integration scenario, some of the problems that arise are outlined and possible solutions are proposed.

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