Handover Management Optimization for LTE Terrestrial Network with Satellite Backhaul

Michael Crosnier [a b], Fabrice Planchou [a], Riadh Dhaou [b], André-Luc Beylot [b]
[a] EADS Astrium, 31 avenue des cosmonautes, 31402 Toulouse Cedex 04, France
[b] University of Toulouse, IRIT-ENSEEIHT, 2 rue Charles Camichel, BP7122, 31071 Toulouse Cedex 7, France

Abstract— **Long Term Evolution (LTE) prevails as the next 4th generation of mobile communications. Hybrid satellite and terrestrial LTE network takes advantages from the large satellite coverage for several emergency applications, such as providing civil security communications. In this paper we propose a LTE architecture partly composed of an integrated component with satellite backhaul on the LTE-S1 interface. Since ensuring seamless communications is essential in LTE, we describe an optimization of the handover mechanism adapted to this specific architecture. This paper focuses on the handover between an eNB with a satellite S1 interface and an eNB with a standard terrestrial S1 interface.**

Keywords- Satellite; LTE; handover; hybrid architecture

I. INTRODUCTION AND CONTEXT PRESENTATION

The hybrid composition of satellite and terrestrial mobile networks is a promising approach for the delivery of services, especially in various emergency situations. For instance, the supply of satellite coverage is useful in the domain of civil security. Today services in this domain are based on terrestrial networks such as PMR (Private Mobile Radio). However, civil security needs have evolved and are also more data consuming. The actual PMR does not fulfill the requirements of these new applications. Alternatively, mobile technologies are being continuously enhanced in order to meet the user needs. Indeed the growing demand of throughput consuming applications such as Web2.0, streaming, on-line game has deep impact on data performance requirements of mobile networks. The LTE/SAE (Long Term Evolution / System Architecture Evolution) is the solution of 3GPP to these issues and it is likely to be the next deployed 4G technology. In this paper, we claim that one of the possible 4G-PMR is a LTE-like network. In this context, we propose a LTE network architecture which contains a component with a satellite backhaul (Fig.1). This component is completely integrated in the LTE-PMR network. Thanks to the satellite link, it may be deployable so as to provide communications for the civil security in areas where no infrastructure is available, as isolated region or when a part of the existing infrastructure is destroyed. On the disaster theatre, civil security and rescue teams need communication means, thus a temporary LTE cell may be set up. Configuration time has to be as short as possible. The SONs (Self-Optimizing and self-organizing Network) techniques provide fast and automatic configuration and organization procedures which may allow this type of temporary cell. The integration of a satellite link will significantly impact on the performance of the network. The Evolved Packet Core (EPC) is not suited for a satellite link with long delay and limited resources. LTE specifications consider the EPC as a high speed and low delay network and make the assumption that the radio interface is the critical one whereas EPC links are oversized. These hypotheses are negated by the satellite link integration as backhaul. For example, delay constraints, defined in specifications, are based on an average delay through the EPC and the challenge is focused on the radio interface. Consequently, the S1-satellite segment raises many issues in the LTE network such as security and QoS management over the satellite link, as well as tracking area and handover management. The handover management is a key mechanism in LTE network in order to provide a fast seamless handover to mobile users. Therefore we decide to orient our study toward the intra-LTE handover. In the section II, the LTE network architecture with a satellite backhaul is described. Then in section III, we briefly discuss the standard handover procedure and its inappropriate mechanisms with a satellite backhaul. In section IV our optimizations are introduced. In section V the simulation results are presented and finally, in section VI we conclude.

II. LTE ARCHITECTURE WITH SATELLITE S1-INTERFACE

The chosen LTE architecture is an integrated network with a satellite backhaul as S1-interface. The network is owned by one operator. LTE network has been split into a terrestrial and a satellite component. Two architectures may handle the satellite link. The first one only modifies the eNB (evolved NodeB) in order to tailor mechanisms to the satellite link and reuse the MME (Mobility Management Entity) and SGW (Serving GateWay) of the terrestrial network. However, this solution raises issues such as tracking area and location management because the satellite coverage encompasses eNBs from different localization. In order to solve these problems, we have dedicated core network entities, Sat-MME (Satellite-MME) and Sat-SGW (Satellite-SGW) to the satellite component which allows protocol and mechanism optimizations over the satellite S1-Interface such as a new satellite tracking area procedure. Moreover procedures between both components may be tailored modifying, to the minimum extent, standard terrestrial entities.

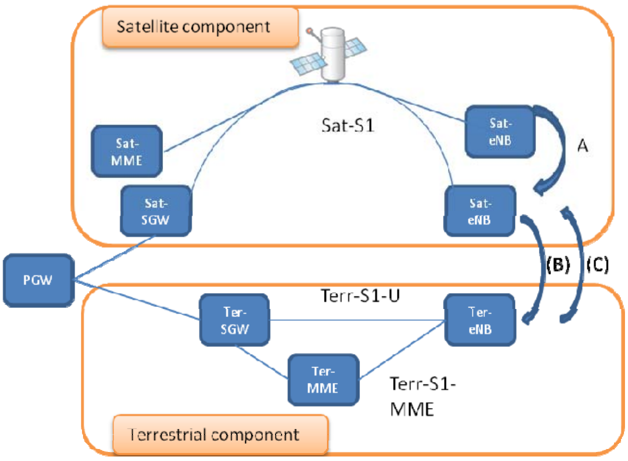

Figure 1. Architecture.

Three types of handover (HO) may be considered: intra-HO between two eNBs from the satellite component (fig.1-A) and two inter-component handovers (fig.1-B), HO from terrestrial to satellite component and from satellite to terrestrial component (fig.1-C). The chosen architecture infers a change of SGW and MME during inter-component handovers. In the following sections, we tailor the handover management of the inter-component HO from satellite to terrestrial S1-interface because standard handover is not optimized and decreases the user performance whereas the handover to a terrestrial component must improve the quality of service.

III. INTRA-HO FROM SATELLITE TO TERRESTRIAL S1-INTERFACE

The handover procedures are defined in LTE specifications [1]. In our architecture, eNBs of the satellite component have no X2-interface to eNBs of the terrestrial component. Moreover the satellite component has specific EPC entities (Sat-MME and Sat-SGW). As a consequence, a S1-handover with MME and SGW relocation occurs. Three issues are raised by this type of handover, the handover decision/preparation, the downlink indirect forwarding tunnel and the uplink path change.

A. *Handover decision/preparation*

The handover decision is made according to measurement reports sent to eNBs by the UE (User Equipment). Afterwards, an exchange of message is performed in order to reserve resources in the target eNBs and to transfer the UE-context (Fig.2). The "Handover Required" and "Handover Command" messages are both sent through the satellite link therefore the handover preparation is delayed and the handover may undergo failure because the decision will be based on obsolete measurement reports. Another problem may occur, since the handover preparation is shorter in the terrestrial component, the signal to interference parameter may be too low in order to send the "Handover Command" from the Sat-eNB to the UE. This causes a reconnection to a neighbor eNB losing the packet located in the EPC and the bearer contexts.

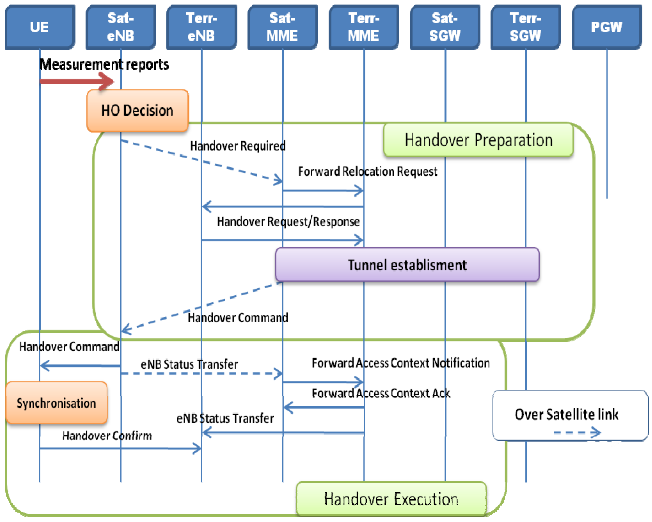

Figure 2. HO preparation and execution

B. *Downlink indirect forwarding tunnel*

An indirect forwarding tunnel may be established between the source SGW (Sat-SGW) and the target SGW (Ter-SGW). The purpose of this tunnel is to forward GTP (GPRS Tunneling Protocol) packets related to non-real-time applications such as TCP traffic to avoid losses and desequencing. The negative impact of reordering on a TCP connection has been studied in [2] [3]. The packets are resent from the source eNB to the source SGW, tunneled to the target SGW and finally forwarded to the target eNB (Fig.3).

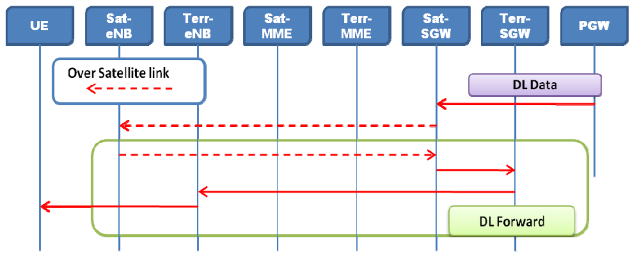

Figure 3. Standard tunnel forwarding

The data path resulting from this mechanism entails a useless back and forth on the satellite S1-interface whereas satellite resources are limited and expensive. Furthermore, this forward mechanism leads to double the delay even if the new eNB is terrestrial.

C. *Uplink path change*

When the UE receives the "Handover Command" message, it starts the handover execution. This phase is very short (about 10ms). Thus, some packets from the Source-eNB are received in the meantime as the ones which are sent after the handover execution through the target eNB. This out-of-order packet delivery is caused by the satellite propagation delay. For TCP traffic, the change of path entails the complete desequencing delivery of TCP sequences. As a result, performance is reduced and resources are unnecessarily consumed, especially for TCP traffics which are sensitive to in-sequence reception. In spite of the UL forwarding, which is optional, this problem remained

IV. PROPOSED OPTIMIZATIONS

In order to avoid the risk of failure due to the long handover preparation, we propose a slight modification of this procedure. The handover decision is dissociated from the handover preparation. An algorithm, with higher threshold values, triggers the handover preparation (Preparation Handover Decision (fig.4).

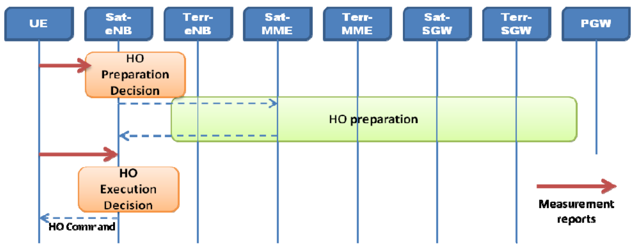

Figure 4. Optimized handover algorithms

Parameters of the algorithms are based on the signal quality measures by the UE and reports to the Sat-eNB. In order to compensate the delay caused by the handover preparation over the satellite link, we will anticipate this phase; hence we increase the threshold values of the algorithms. Then, when the handover preparation ends, the Source-eNB does not send the "Handover Command" message immediately to the UE. Another algorithm provides the decision to trigger the handover execution according to recent measurement reports (Execution Handover Decision). The handover execution phase may be delayed thanks to this second algorithm until signal quality measurement reaches the optimal value. It is necessary to resize timers in order to take into accounts the additional handover delay. $TS1_{reloc}$ timer triggers the handover preparation failure procedure in the Sat-eNB if the handover preparation is too long. $TS1_{relocoverall}$ will verify that the resources within the Sat-eNB are released after the handover completion. This handover preparation reduces the number of handover failure due to decision based on no longer valid measurement reports. In this case, the timer T310 triggers the connection re-establishment procedure. These timers are defined in [2].

The standard indirect forward tunneling is not efficient for this handover. Therefore, the proposed solution forwards packets directly from the Sat-SGW to the Ter-SGW avoiding the back and forth on the satellite link. The Sat-eNB does no longer need to create the tunnel to the Sat-SGW. This solution leads to the loss of all the packets which are being transferred over the satellite link (S1-User Interface). The idea is to resend the GTP packets that are not received by the UE. Since GTP-U does not perform any control, the Sat-SGW needs to allocate a buffer during the handover preparation and to store all the packets which are received in a time period equal to the satellite delay plus the handover execution duration and the transmission time over the radio interface. This delay will be an estimation based on an as accurate as possible estimation. An improper estimation of this delay will trigger TCP congestion mechanisms because an undersized or oversized estimation will respectively infer packet losses or packet duplications. Therefore the buffer will be slightly oversized and a new mechanism within the Sat-SGW will discard duplicated packets. Thus, the Sat-eNB will inform the Sat-SGW of the last received GTP sequence number thanks to the "handover command/confirm" message. During the handover execution phase, the Sat-eNB sends information (eNB status) in order to keep the PDCP (Packet Data Convergence Protocol [3]) context to the Ter-eNB through the MMEs. PDCP context consists of sequence numbers over the radio interface only. This message will be send through the satellite link. Consequently the handover is performed prior to the eNB status reception and this information is outdated and useless for the Ter-eNB. The UE may transmit the eNB status in an RRC message (over the radio interface) and add to the PDCP sequence numbers the corresponding GTP sequence numbers. Since the handover preparation does not consistently infer that the handover command will be immediately sent to the UE (Execution Handover Decision), the data forwarding tunnel cannot be established during the handover preparation as in the standard S1-handover. A new GTP-C message is created between the Sat-MME and the Sat-SGW, named "Data Forward Activation". When the Sat-SGW receives this message, it will begin sending the data stored in the forwarding satellite buffer. This message consists of GTP sequence numbers of the different bearers that have been already received by the UE. The Sat-SGW will discard all packets within the satellite buffer with a lower sequence number in order to avoid packet duplication. However the "Handover Command" may be received by the UE prior to GTP-U packets send before the satellite buffer creation. Indeed, control messages have priority above user data message. Thus a small amount of packets may be lost despite data forwarding. The Sat-SGW will inform the Sat-eNB of the last GTP-U packet for each forwarded bearer sending an end-marker GTP message at the satellite buffer creation.

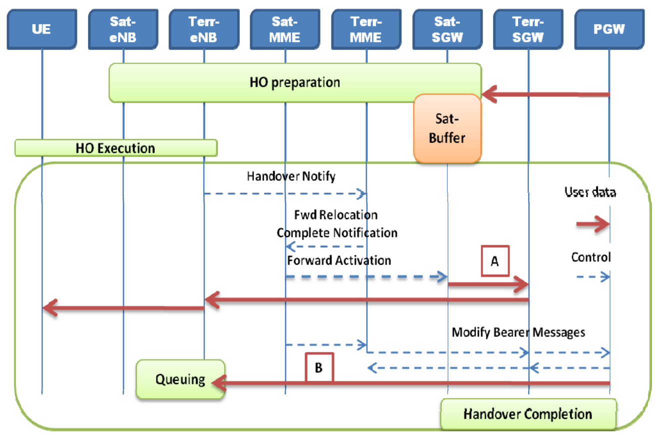

Figure 5. Tunnel forwarding optimization

The "HO Execution Decision" will trigger the handover after the reception of all the end-marker for each bearer. Since end-marker messages using the GTP-U protocol, they will be received only after the last user data packets sent prior to the sat-buffer creation. The forwarding mechanisms entail queuing problems within the Ter-eNB. After the handover execution, the Ter-eNB will enqueue non-tunnel packets (fig.5-B) until the end of tunneled packets (fig.5-A) (i.e., Sat-buffer will be empty). The amount of queued packets is quite higher than in a standard terrestrial handover. Therefore the Ter-eNB may discard packets and decrease TCP performances.

On the uplink, during the handover completion, two mechanisms are proposed in order to improve TCP performance and avoid out of sequence delivery. The GTP packets from the Sat-eNB have to be discarded by the Sat-SGW and TCP will handle losses of the packets transmitted through the satellite link, so even for lossless handover we allow GTP packet losses. The second proposed mechanism is a UL forward tunnel. The Sat-SGW tunneled packets from Sat-eNB to Ter-SGW. This solution leads to buffer the UL packets from the Ter-eNB in the Ter-SGW until the last UL packet from the Sat-eNB is received thanks to an end marker. The second solution will impact the terrestrial network in order to ensure in-order delivery of UL packets creating buffer in the Ter-SGW, therefore we choose to avoid this solution and select the discarding solution. Besides the solution is much simpler and less resource consuming in the terrestrial core network and it will be sufficient for UL TCP application needs.

V. SIMULATION

In order to appraise the different proposed optimizations, we have performed simulations thanks to the ns3 simulator. Simplified user plane protocol (GTP-U) and control plane protocols (GTP-C and S1AP) have been implemented. Indeed only control messages exchanged during the S1-handover procedure are defined, then we assume that no control messages are lost during the handover procedure. Because of a lack of LTE simulation tools, the radio interface is only simulated thanks to delay and throughput values and no RLC or MAC mechanisms are performed. As well, the satellite link is only simulated thanks to a large delay which is the most troublesome parameter in our scenario. In the figure 6 only user plane is described

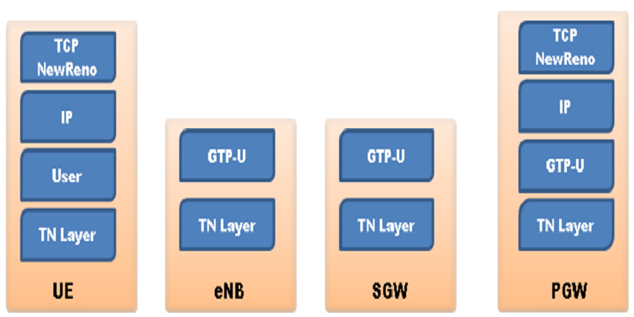

Figure 6. User plane for NS3 simulation

Simulations have been focused over the tunnel management optimization and TCP performances improvements during the handover. We compared results between three handover procedures:

- No tunnel management and no data forwarding (all user packets will be lost during the handover execution and completion).
- Standard tunnel procedure with the back and forth over the S1-satellite interface.
- Optimized tunnel procedure to S1-satellite interface.

The application for the simulation is a file transfer using the TCP New Reno protocol above IP. The IP packet is encapsulated in LTE protocol thanks to an ns3 VirtualNetDevice module. The transport network layer (TNL) is a protocol stack consisted of UDP/IP protocols and a NS3 PointToPointNetDevice module. The channel throughput value over the radio interface is 1Mbps and the S1 satellite is defined thanks to a delay of 300ms and a data rate of 512kbps.

The handover procedure is triggered by a message sent by the simulator. Since no access layers are implemented, there are no radio measurements and no simulations of the handover decision algorithms. Besides, in order to handle GTP packet ordering during the handover completion, we have implemented two queues in the Ter-eNB: one for tunneled packets and one for non-tunneled packets.

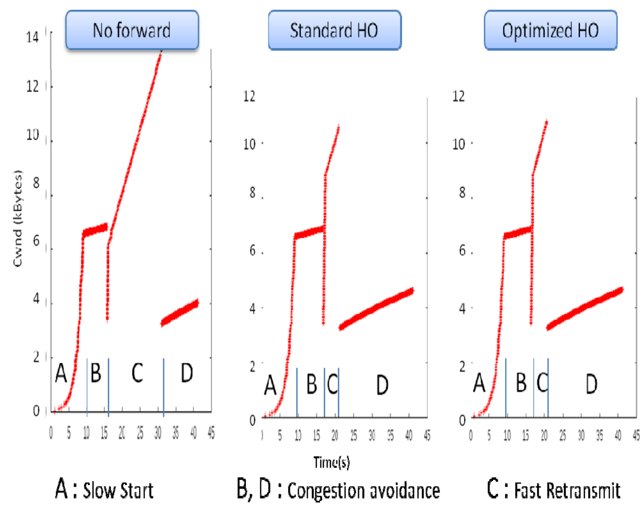

Figure 7. TCP congestion windows evlolution

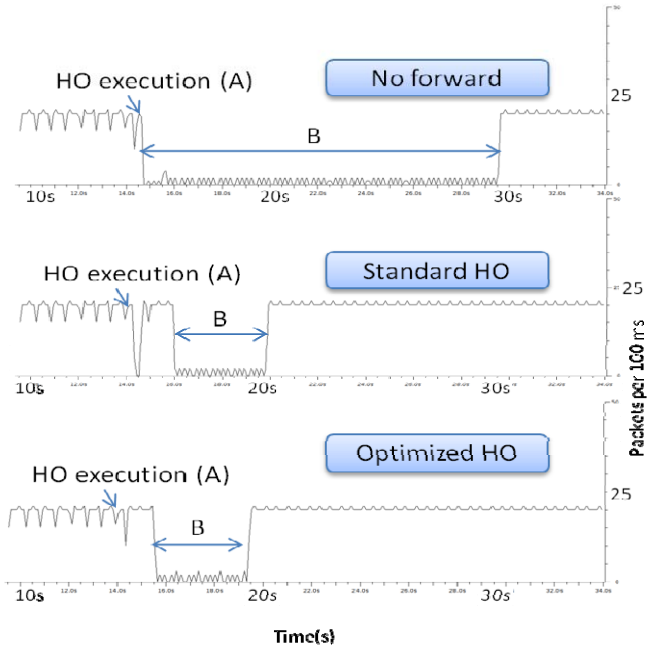

Figure 8. Evolution of received packets by the UE.

The figure 7 shows the congestion window of the TCP New Reno protocol during the different handover procedures. There is no major difference between optimized and standard procedure, both of them handle successfully the handover. However thanks to the optimized procedure we have saved half of the bandwidth of the satellite consumed by each forwarded bearer and an additional satellite transmission delay is avoided. Since tunneled packets are earlier received by the UE during an optimized S1-handover than during a standard S1-handover, performance is slightly improved. Nevertheless, during the "handover completion", TCP protocol experiences segment losses, identified by B on the figures 7 and 8. Indeed, after the handover execution, the UE will send an acknowledgement of a large amount of the TCP congestion window, therefore a large burst of packet will be sent and create congestion. Packet excess will be discarded either in the PGW (Packet data network GateWay) which limits the ingress traffic or in the eNB thanks to the packet discarding mechanisms in the PDCP layer (Packet Data Convergence Protocol [3]). In our simulation, PDCP discarding is simulated thanks to the two queues located in the Ter-eNB. As a consequence the TCP New Reno performed Fast Retransmit procedure (fig.7 (B)) and after the retransmission of lost segments, TCP protocol will reduce the congestion window to a more appropriate one for the terrestrial component. Since we cannot avoid TCP packet losses without TCP modifications with cross layer mechanisms as described in [6], a handover without any tunneling forwarding may seem less resource consuming. However, the figures 7 and 8 highlight the higher performances of the optimized handover procedure. The fast-retransmit is longer for the non-tunneled procedure because all packets which are transmitted over the satellite interface will be lost whereas fewer packets will be discarded during the optimized handover

VI. CONCLUSION

In this paper, we have proposed a hybrid LTE network architecture and studied a new handover mechanism from satellite to terrestrial component. We have dissociated the algorithms to trigger the handover preparation from the handover execution. Then, we have tailored the preparation phase and the tunnel management in order to provide better performance according to the user application point of view, such as TCP-based applications. Despite packet losses, the proposed optimized handover procedure provides higher performances than standard S1-handover. In order to validate the overall handover optimization, simulations need to be run with an implementation of radio interface access layer. Besides other challenges are raised and need to be solved such as other handovers which include the satellite component as well as tracking area and QoS management.

REFERENCES

[1] 3GPP TS 23.401 "GPRS enhancements for Evolved Universal Terrestrial Radio Access Network (E- UTRAN) access", version 10, Sept. 2010.

[2] 3GPP TS 36.331 "Radio Resource Control (RRC); Protocol specification (Release 10)", version 10.0.0, December 2010.

[3] 3GPP TS 36.323 "Packet Data Convergence Protocol (PDCP) specification (Release 10) , version 10.0.0, December 2010.

[4] D. Pacificio, M. Pacificio, C. Fischione, H. Hjelrmasson, K. H. Johansson, "Improving TCP Performance During the Intra LTE Handover", Global Telecommunications Conference, Dec. 2009

[5] A. Racz, A. Temesvary, N. Reider, "Handover Performance in 3GPP Long Term Evolution (LTE) Systems", Mobile and wireless Communications Summit, July 2007.

[6] MinSu Shin, ManKyu Park, DeockGil Oh, byungChul Kim, JaeYong Lee, "Practical Vertical Handover Mechanisms between Satellite and Terrestrial Networks", Smart Spaces and Newt Generation Wired/wireless Networking, ruSMART/NEW2AN , August 2010