Wireless mesh backhauling for LTE/LTE-A networks

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***Abstract*—It has been recognized that effective communications and the ability to share various media are keys to a successful operation in public safety and military applications. LTE (Long Term Evolution) is becoming the most widely deployed broadband communication technology making it the technology of choice for public safety to replace TETRA and similar networks. However, LTE is a cellular network by design in that it has planned and fixed antenna locations, and is connected to a common packet core network. Even though the LTE self-organized operation makes the planning, configuration, management, optimization and healing of the network simpler and faster, LTE networks are not well-suited for the moving cell, particularly to establish the backhaul link among the base stations. In this paper we present a novel concept of enhanced evolved Node B (e2NB) to enable meshing of the neighboring e2NBs and maintain the LTE-compliant communication service with the legacy terminals reusing the LTE air interface while moving. We evaluate the performance of the e2NB in terms of backhaul link performance and end-to-end communication using the OpenAirInterface (OAI) LTE implementation. Emulation results demonstrate the feasibility of the proposed approach to build a self-organized mesh network over LTE/LTE-A. They also show that LTE quality-of-service requirements can be maintained in multi-hop networks subject to resource allocation across multiple e2NBs.**

***Index Terms*—4G mobile communication, Wireless mesh networks, Network Topology**

I. Introduction

A. Motivation

LTE 4G cellular networks are gradually being adopted by all major operators in the world and are expected to rule the cellular landscape at least for the current decade. Several new approaches and technologies are being considered as potential elements to make up towards fifth generation mobile networks and unlock the multiple emerging use cases [1]. In particular, mobile backhauling, multi-hop routing, full duplex radios, and smart carrier aggregations are among the main enablers for the moving cell scenarios found in public safety network (PSN), intelligent transport system (ITS) and military applications [2]–[4]. This is because the planning of the point-to-point wireless backhaul link may often be too costly or not possible to be established among moving and/or static cells. Currently, an interface named X2 is used in 3GPP/LTE to coordinate base stations (evolved Node B - eNB) and assist user equipments (UEs) handover procedure under ideal and non-ideal backhaul links (cf. 3GPP 36.842). One typical scenario in moving cells is that of core-isolated eNBs (e.g. due to mobility), which is under study in 3GPP to extend eNB capabilities in order to maintain basic services to users (cf. 3GPP 22.897). Connectivity remains limited to one eNB or to a subset of eNBs that are still connected to each other through a part of the backhaul network. However, re-establishing the communication among different network partitions when eNBs are within a radio proximity of each other remains an open problem.

Research leading to these results received funding from DCNS.

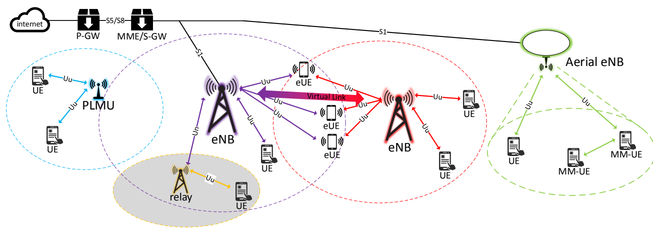


Fig. 1. Current network topologies in support of mobile backhauling

Several approaches have been proposed in the literature. Fig. 1 illustrates possible network topologies achievable with the currently available systems. One hop relaying is the basic mechanism in standard LTE to extend the coverage and/or capacity allowing a relay node (RN) to be associated with an eNB [5]. A classical eNB can then serve its UEs in one or two hops depending on whether a relay is used or not. Some studies demonstrate the gain of two hops chained relays (i.e three hops from eNB to UE) without providing the required changes in the standard [6]. More recent works propose new eNB concepts like the aerial-eNB [7] or the hybrid-eNB [8], but do not address the problem of over-the-air LTE links connecting eNBs to each other. An aerial eNB can indeed provide LTE coverage to an extended area but need to rely on another technology for its backhaul access. New devices named portable land mobile units (PLMU) include one standalone eNB that can serve its UEs locally without connectivity to an external EPC. They can also be connected to other PLMUs through a satellite backhaul thus providing inter-eNB connectivity [7]. Another recent work introduces the concept of evolved UEs (eUEs) as active network elements to interconnect eNBs through cooperative L2 relaying [9]. While this approach enables over-the-air re-establishment of inter-eNB links using LTE, it requires new types of UEs and incentive mechanisms for the participation of batterypowered eUEs in the network operation. Possibly, a device could assume several of the previous roles.

However, none of the above approaches provides a true meshing among moving eNBs without significant changes in the existing LTE components. In addition, the communication services are dependent of the connectivity with the packet core network through S1 interface. This calls for self-organized wireless mesh backhauling for LTE/LTE-A network that leverages the existing air interface to establish the inter-eNB links.

B. Contribution

In order to build an over-the-air self-organized LTE mesh network among neighboring eNBs while maintaining support for classical UEs, we present a novel architecture that enhances eNB, denoted as e2NB. The main idea is to leverage the existing LTE air interface to enable inter-eNBs communication with a single TX/RX transmitter without any modification to the current LTE components and protocols. However, the performance can be increased if multiple TX/RX chains, full duplex radios, and/or carrier aggregations are available. For this purpose, eNB is enhanced with two additional functions (patent pending), namely:

1) Virtual UE (vUE): deployed as a service by the e2NB to establish a connection with the selected neighboring e2NB over the Uu (eNB - UE) and Un (eNB - relay) interfaces. It leverages the techniques used by LTE relays to preserve communication to classical UEs.
2) Network coordination and orchestration entity (COE): manages the embedded entities of a e2NB and the resulting network topology.

The remainder of this paper is organized as follows. Section II presents the target network topology and the associated requirements. Section III introduces the concept of e2NB, describes its designed elements and functions to address the requirements of public safety and military applications as well as the constraints imposed by LTE itself. Section IV provides the experimental results supporting the feasibility of e2NB and assessing its performance. Finally, Section V presents the concluding remarks and future directions.

II. Network Topology and Requirements

The primary design goal of the e2NB is to reuse the existing LTE air interface to establish over-the-air inter-eNB communications in moving cells scenarios such as communications inside a marine fleet or between military troops. Fig. 2 shows an example of a targeted network topology that consists of a set of e2NBs without a common backhaul network (e.g. a satellite link). Those e2NBs must dynamically form a self-organized mesh network, and perform a routing and data forwarding in a multi-hop fashion. To this end, the main requirements of an e2NB can be summarized as follows:

1) Establish a wireless communication link with each neighboring e2NB node using one or multiple Tx/Rx radio chain(s);
2) Preserve the services to standard mobile entities (UEs);

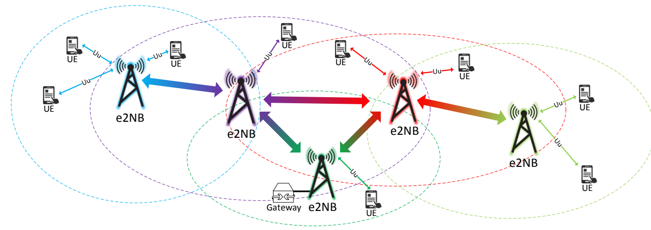


Fig. 2. Target network topology

3) Provide a gateway service by attaching as a UE to an existing LTE network infrastructure when available;
4) Route the data in multi-hop fashion with arbitrary topology.

It can be seen that the current LTE network architecture is not sufficient to address the first and third requirements. The fourth can be partially achieved with a central eNB/EPC and relay nodes (i.e. resulting in a 2 hops star topology), where all the communications are managed by the central entity. As for the second requirement, it can be easily fulfilled by a standard LTE system.

III. Enhanced Evolved Node B (e2NB)

This section introduces the e2NB as an enhanced version of the standard LTE/LTE-A eNB, describes its components and elaborates on how the previously mentioned requirements are met.

A. Components

An e2NB reuses the existing LTE components but with a different composition to meet the requirements stated in Section II. The minimal involved components include:

- Single eNB;
- Single MME (Mobility Management Entity);
- Single HSS (Home Subscriber Server);
- Multiple UEs as a service, denoted as virtual UEs (vUEs);
- one radio chain (Tx/Rx).

Depending on the target deployment and use case, the remaining LTE components such as S/P-GW (Serving and Packet Data Network Gateway), PCRF (Policy and Charging Rules Function), may also be included in e2NB. Moreover, an e2NB requires two additional functions, namely:

- Coordination and Orchestration Entity (COE);
- Routing and data forwarding.

B. Protocol Stack

These components are not working independently and have several relationships that can be modeled as the protocol stack shown in Fig. 3. It can be seen that an e2NB preserves the existing eNB and UE functions in that it does not modify the protocol stack of the embedded eNB and UEs. To enable a standalone operational mode, an e2NB also requires the NAS (Non Access Stratum) and routing protocols. The COE acts as a connectivity manager coordinating all these layers to enable the inter-e2NB communications as well as a topology manager working with the other COEs to optimize the network.

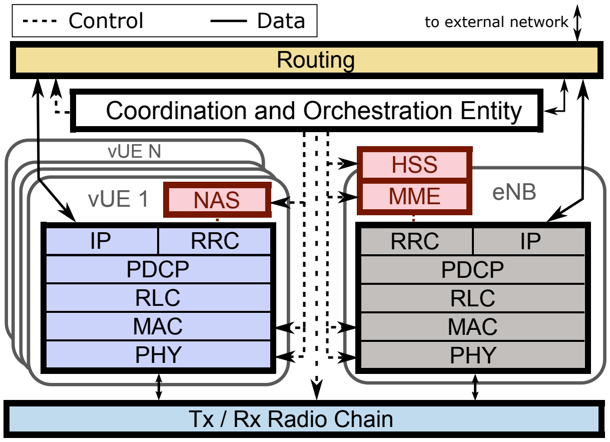


Fig. 3. Enhanced Evolved Node B (e2NB) Stack

In the following, we describe the role of each component of the e2NB.

1) eNB: provides the same operations as in a legacy 3GPP eNB in that it communicates with UEs through the legacy Uu air interface and with MME and optionally S-GW through the legacy S1 interface [10].

2) MME and HSS: allow the e2NB standalone functionality and they interact with the embedded eNB. The HSS includes a database of authorized users on the network and can be accessed through the S6a interface.

3) vUEs: establish the inter-eNB communications. A vUE includes the entire protocol stack of a legacy UE required to establish a communication with an eNB. It is used to detect the existence of an e2NB in the radio vicinity, to report the real-time radio information such as received signal strength to the COE, and to establish a connection when instructed by the COE.

4) Routing: enables a fast routing and data forwarding at the e2NB. S/P-GW are bypassed. This allows an e2NB to send and receive IP packets directly from the eNB and vUEs PDCP layer and to perform (local) routing for each packet. Contrary to classical eNBs, an e2NB can act as an end point (e. g. gateway) and have external interfaces to be connected to other networks. The routing protocol determines data forwarding paths according to the rules provided by the COE.

5) COE: manages the entire life-cycle of vUEs from the configuration and deployment to runtime management and disposal. It provides each of them with a IMEI and a SIM service (IMSI + cryptographic functions), allowing them to be authenticated by the other e2NBs. In addition, the COE keeps track of the e2NB connectivity (via its own vUEs and those of neighboring e2NBs connected to its eNB). This helps it to cooperate with other COEs in order to optimize the resource allocation across multiple e2NBs and to manage the topology in terms of network split and merge. The COE also determines the IP addressing space and provides routes according to adhoc/mesh routing algorithms. It can be seen as a local controller and could be designed following the software-define networking (SDN) principles. Finally, the COE is controlling the access to the radio front-end required by both the embedded eNB and vUEs.

C. Frame Organization (Frequency Division Duplex case)

In FDD (also in TDD), an eNB has several predefined procedures regarding what it should transmit or not in the subframes (SF - 1ms length) of a frame (10ms length). First, it has to transmit the first OFDM symbols on every SF for the control channels, namely Physical Downlink Control Channel (PDCCH), Physical Control Format Indicator Channel (PCFICH), and Physical Hybrid-ARQ Indicator Channel (PHICH). Primary and Secondary Synchronization Signals (PSS and SSS) must be transmitted in the SFs number 0 and 5 (in FDD) along with the Physical Broadcast Channel (PBCH) in SF number 0. Finally, it must transmit reference signals (RS) on all downlink (DL) SFs, even if there is no data to transmit on the Physical Downlink Shared Channel (PDSCH).

The solution choosen by the relay nodes to enable communication with their Donor eNB (DeNB) while maintaining compatibility with Rel.8 UEs is to make use of Multicast-Broadcast Single-Frequency Network (MBSFN) SFs [5], [11]. The MBSFN SFs allow an eNB/relay to send the first symbols containing PDCCH, PCFICH and PHICH while not sending the other symbols including the RS. New control and data channels (R-PDCCH and R-PDSCH) are introduced to use the empty symbols in the MBSFN SFs for the DL communication, i.e. from DeNB to relay. For the relay to DeNB communication, the relays determine which uplink (UL) SFs have to be used for the communication with their DeNB and then use the remaining ones for the UE-to-relay communication. In FDD DL, only SFs number 1, 2, 3, 6, 7 and 8 can be used as MBSFN SFs. A relay can use the corresponding UL SFs (i.e. DL SF # + 4) to perform UL transmissions to the DeNB. Thus, a relay performs a DL transmission to legacy UEs on SFs number 0, 4, 5, 9 and on the MBSFN SFs that are not used for the relay to DeNB link (also called backhaul link). In UL, a relay receives on SF number 3, 4, 8, 9 and those not used in MBSFN SFs # + 4 (as UL SFs are scheduled at DL SF # + 4). The e2NB applies the same solution as relays to maintain compatibility with the legacy UEs, and uses the MBSFN SFs to give its vUEs access to the DL channel. Then, the vUEs can receive on the MBSFN SFs that are not in use by the embedded eNB, i.e. SF number 1, 2, 3, 6, 7 and 8. This limits the maximum number of DL SFs an e2NB can receive through all its vUEs to 6. In UL, vUEs can send at DL SF # + 4 after receiving downlink control information (DCI) with UL grant as in case of legacy UE. This leads also to a limit of 6 UL SFs per e2NB for all their vUEs.

D. Hybrid ARQ

The e2NB HARQ mechanisms remain unchanged with respect to the relaying case. For DL, the e2NB expects to receive the ACK/NACK for both legacy UEs as well as vUEs 4ms after the transmission, and in case of NACK the retransmission will be determined by the e2NB. For UL, HARQ acknowledgments are transmitted on PHICH for regular UEs and on R-PDCCH for the vUEs. However, the SF where the retransmission should take place (8 ms after the initial transmission for FDD) may not be available for the

UL transmission (e.g. e2NB is using the UL channel for its vUEs), even if the HARQ ACK can be received. In such a case, the corresponding UL HARQ process needs to be postponed by transmitting an ACK on the PHICH, irrespective of the outcome of the decoding [12]. By using PDCCH, an adaptive retransmission can instead be requested in a later SF available for the same HARQ process. Note that in such a case, the HARQ round-trip time will be larger than 8ms.

Because vUEs can only receive up to 6 UL SFs per frame, it is not efficient to keep the 8 HARQ processes cycle as for the legacy UEs. In particular, when the available MBSFN SFs are determined for a configured repetition period (i.e. fixed SF allocation), the COE will adjust the number of HARQ processes to the number of available UL SFs for a vUE.

E. vUE Attach Procedure

Contrary to the relay that first connects to its DeNB before starting to serve UEs and thus has full access to the DL channel, an e2NB must be able to dynamically start a connection with a neighboring e2NB without dropping the UEs it is serving. The classical UE attachment and authentication procedures remain the same but they influence the way the COE manages the embedded eNB. A vUE needs to listen at least to PSS, SSS, MIB (in PBCH), and SIB1 to detect and identify an eNB, as well as the SIB2 to start a random access procedure. In FDD, PSS and PBCH are broadcasted on SF 0, SSS and SIB1 on SF 5, and SIB2 location is given by SIB1. If the eNBs of different e2NBs are frame synchronized, the SFs are used by the neighboring eNBs at the same time and thus a vUE listening on MBSFN SFs would not be able to detect a neighboring e2NB. In addition, a vUE needs to access the PDCCH to decode SIB1 and SIB2, which is not possible by just blanking some of the available MBSFN SFs. To address this problem, e2NB blanks an entire 10ms frame allowing a vUE to listen to the DL channel and to receive these elements from the neighboring e2NB. Blanking a full frame is feasible in LTE and does not result in a UE and/or vUE disconnection. A UE/vUE becomes out-of-sync if it does not receive anything during a period defined as $200ms * N310 + T310$, with the value of N310 [1] and T310 [2] signaled in SIB2. e2NB applies several blank frames in time to proceed with the full attachment to a neighboring e2NB. The eNB timings related to the UE/vUE random access may be loosen to reduce the frame blanking periodicity of the connecting e2NB. The vUE uses pre-defined authentication keys that are shared by all HSS of e2NBs planned to be interconnected during the operation (e.g. e2NBs of the same group). It allows the e2NBs to identify the vUEs and the group they belong to so that the appropriate policies can be applied before establishing the connection.

F. Synchronization

Contrary to relays that have only one backhaul link, an e2NB manages several vUEs that are connected to different e2NBs. It also has vUEs of other e2NBs connected to its eNB. Fixed relays are not necessarily synchronized at symbol-level with their DeNB. It allows them to compensate the propagation delay, and as a result increases the total number of symbols a relay can receive over a SF. Although this can work in a tree topology, it is mandatory to be symbol synchronized in a mesh topology. If e2NBs are not synchronized and rely only on the timing advance of one to another, then the SFs symbol alignment may be broken across e2NBs causing backhaul link failure [5]. To synchronize, each incoming e2NB willing to join the mesh network uses its vUE to determine the time reference of the network.

G. Handover

Terminal mobility may trigger a handover among the meshed e2NBs. Upon reception of the measurement report, an e2NB may initiate an X2 handover as in the standard X2 handover procedure. However, it also requires to transfer the HSS context to the target e2NB in addition to the security context so that the handed over UE can be authenticated and reattached in case of disconnection.

H. Resource Allocation: CoE and MAC

As long as an e2NB has a connectivity with at least another e2NB, the COE needs to determine the efficient time and frequency share of spectral resources among the neighboring e2NBs to achieve a near optimal performance. The COE must be aware of the allocation of neighboring e2NBs to avoid interferences and coordinate transmissions efficiently. For instance, an e2NB can send to several vUEs on one SF. This e2NB must know that these vUEs are listening at that time. Plus, the neighboring e2NBs of the receiving vUEs must not transmit on this SF (except in case of beam-forming) to avoid interferences. The COE then needs to apply the configured allocation to its vUEs and eNB schedulers and needs to control the access to the RF front-end accordingly.

IV. Evaluation

We conduct several experiments based on the OpenAir-Interface (OAI) built-in emulation platform [13], [14]. This platform implements standard compliant LTE UE and eNB protocol stacks spanning all the layers from PHY to RRC. For the PHY layer we use the "full PHY mode" that generates real I/Q samples after modulation. It performs the convolution of these samples with a synthetic channel to simulate the influence of the RF chains and propagation channel on the signal, instead of sending them to a RF card. The resulting samples are given to the demodulator of the receiving node. It is the only part that differs from a real LTE system as we use all the other LTE layers in a classical way.

Fig. 4 shows the considered network topology for three experiments. The first two experiments characterize the performance of the backhaul link between two e2NBs (labeled (a) and (b)) for fixed and moving cell scenarios. The initial positions of the e2NBs, and their target destinations for the moving cell scenario are shown in Fig. 4. The last experiment

[1]This parameter indicates the number of times in which the UE cannot successfully decode any frame in 20 consecutive frames (200ms).

[2]A timer, in seconds, used to allow a UE to get back in synchronization with the eNodeB.

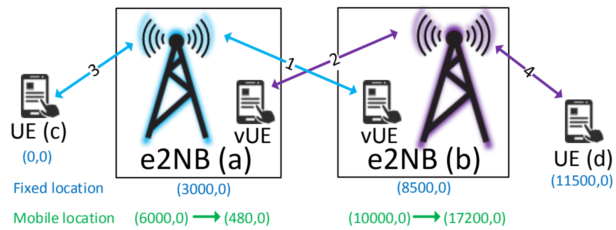


Fig. 4. Network topology

TABLE I
EMULATION PARAMETERS

Parameter	Value	Parameter	Value
Carrier Freq.	0.9 GHz	*Max. Tx Pwr (dBm)*	eNB 24.7 - (v)UE 23
Bandwidth	5 MHz	*Max. MCS*	DL 26 - UL 16
Pathloss at 1km	-91dB	*RLC Mode*	UM
Pathloss Exp.	3	*RLC reorder. timer*	35ms
Noise Model	AWGN	*SR Periodicity*	2ms - even SF only
Trans. Mode	1	*Packet IDT*	uniform 10-50 ms
Antenna	Omni 0dBi	*Packet Size*	uniform 64-1408 bytes

evaluates the performance of multi-hop data forwarding between two UEs ((c) and (d)) via the fixed e2NBs ((a) and (b)). A summary of emulation parameters is provided in Table I.

Due to platform constraints, we make two assumptions that differ from the real case: (a) the propagation delay is close to zero, and (b) Tx/Rx switching time is close to zero. The later is required to use a Uu interface between the e2NBs and the vUEs, instead of a Un interface. The main difference compared to the real case is that the maximum data rate is increased as we can use more symbols per SF for the data plane.

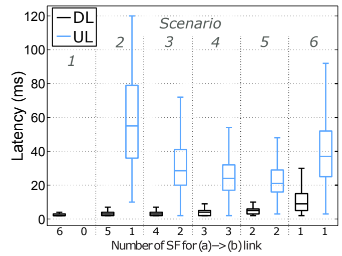
A. Fixed Cells

The first experiment is built around two e2NBs without any connected UEs. Table II shows the different scenarios used in this experiment, with different SF allocation for each link. The SF allocations are fixed for each run of the emulator.

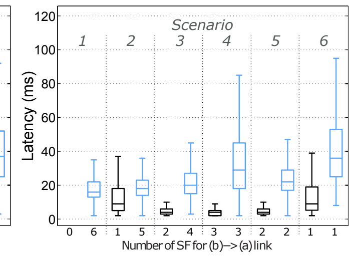
TABLE II
SF ALLOCATIONS

Scenario	DL SF (a) → (b)	DL SF (b) → (a)	Total DL/UL SFs
1	1, 2, 3, 6, 7, 8	none	6/6
2	1, 2, 6, 7, 8	3	6/6
3	1, 2, 6, 7	3, 8	6/6
4	1, 2, 6	3, 7, 8	6/6
5	1, 6	3, 8	4/4
6	6	8	2/2

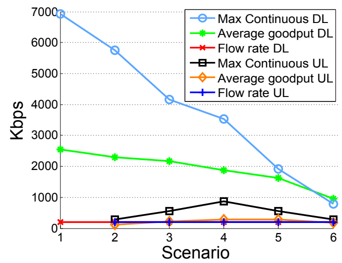
As shown in Fig. 4, the two e2NBs are connected to each other with the help of their respective vUEs establishing links 1 and 2. The only exception is scenario 1, where only link 1 is established (due to the SF allocation). The initial attach procedure is already completed when we start a Variable Bit Rate (VBR) traffic flow on each available data path between the e2NBs, i.e. two for scenario 1, four for other scenarios: (a) to (b) DL (link #1), (a) to (b) UL (link #2), (b) to (a) DL (link #2) and (b) to (a) UL (link #1). The packet size and inter departure time distributions are shown in Table I, while the duration of the flow is one minute. Finally, both e2NBs apply dynamic scheduling.



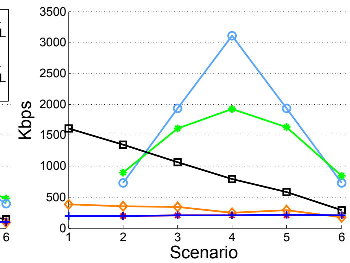
***(E)** Latency (a) → (b)*



***(F)** Latency (b) → (a)*



***(G)** Data rates (a) → (b)*



***(H)** Data rates (b) → (a)*

Fig. 5. Performance of inter-e2NB backhaul link

Fig. 5 (E) and (F) present for each scenario the packet latency of UL and DL flows as box plots [3] , (E) from (a) to (b) and (F) from (b) to (a). Fig. 5 (G) and (H) present for links from (a) to (b) and from (b) to (a), respectively, the average of instantaneous goodputs (packet size over packet transfer time) and the traffic flow rates for the VBR flow, as well as the measured maximum data rate under full load.

It can be seen that the latency, goodput and maximum datarate improve as the number of available DL or UL SFs increases. However, regardless of the number of allocated SFs, the latency is significantly lower over a DL path than over a UL path, which provides much higher goodput in DL. This is mainly due to the UL signaling overhead of dynamic scheduling (scheduling request (SR) and scheduling grant prior to data transmission). Moreover, we can observe that the performance vary for the same number of allocated UL SFs depending on their position. For instance in scenario 4, UL latency is better and with less jitter over (a)→(b) path than over (b)→(a). The same applies for the (a)→(b) UL path in scenario 2 versus scenario 6. This is due to the UL SF of scenario 2 (SF #7) being an odd SF that can not be used to transmit a SR. One conclusion that can be drawn is that the SF allocation as well as the balance of UL and DL paths, determined by the COE, play a key role in the achievable performance. To meet the application QoS requirements, such allocation has to be dynamically adjusted to operate semi-persistently or dynamically for all the data bearers depending on their spatio-temporal traffic patterns.

B. Moving Cells

In this experiment, e2NB (a) and (b) are moving in opposite directions starting from 4km to 17.2km distance with a maximum speed of 20m/s relative to ground. Both e2NBs reach their destination after 400 seconds. The SF allocation of scenario 4 from Table II is used. Two types of traffic are

[3] The box is limited by first (q1) and third quartile (q3) and contains the median. Whiskers extend from $q1-1,5*(q3-q1)$ to $q3+1,5*(q3-q1)$.

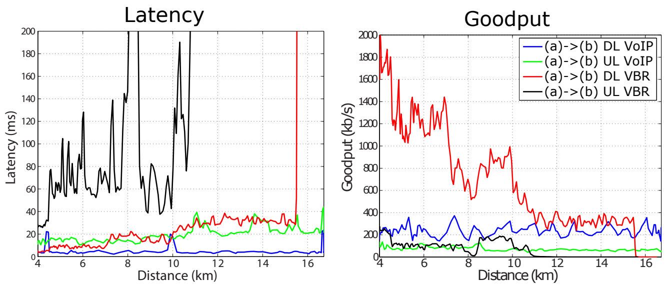


Fig. 6. Performance of inter-e2NB connectivity on the move

considered: VBR with the same packet size and IDT as stated in Table I, and VoIP G729. Each traffic is generated two times from (a) to (b), one on the DL path (link #1) and the other on the UL path (link #2).

Fig. 6 plots the moving averages of the latency and instantaneous goodput as functions of the distance separating the e2NBs from each other.

It can be observed that the latency and goodput of the DL path is significantly better than the UL, especially for the VBR traffic. We note that the system is not able to maintain the VBR traffic on the DL path after a distance of 15.5km and on the UL path after 10km. This is due to two factors: lack of capacity caused by the adaptive MCS that requires more resource blocks to satisfy the VBR data rate and transmission errors due to channel degradation. On UL, the losses start earlier as the capacity is UL is smaller than that of DL.

From the Fig. 6, we see that using either the DL or UL path the LTE QoS requirement of 100ms latency for VoIP is met over the whole experiment.

C. Multi-hop operation

In the last experiment, e2NB (a) and (b) are fixed and connected to UE (c) and (d), respectively (see Fig. 4). Static routes are added allowing to forward the data toward the destination in a multi-hop fashion following different combination of DL and UL links. We also reuse the SF allocation of scenario 4 for this experiment.

As in the previous experiment, both VBR and VoIP G729 traffic patterns are generated. We run several emulation with each time a different combination of links. First from (c) to (a) to get the performance of the first hop (classical UE UL). Then from (c) to (d) (3 hops) with the second hop between (a) and (b) using first a DL path and second a UL path. Finally, with VoIP G729 traffic pattern, we configure additional hops between (a) and (b) to simulate a wider network.

The results are shown in Fig. 7 in the form of a complementary CDF (CCDF) plot, where each latency value in the plot displays the fraction of traffic with latency greater than that value.

We can see that the end-to-end latency is almost doubled when using a UL path over a DL one for the VBR flows, confirming the previous results. Although the SF allocation of e2NBs is different, the two ways behave similarly on the end-to-end point of view. It can be seen that all the tested cases are efficient enough to satisfy the LTE QoS requirement of 100ms latency for VoIP. Using two e2NB UL hops (four hops end-to-end) is close to the limit and using a third one would not

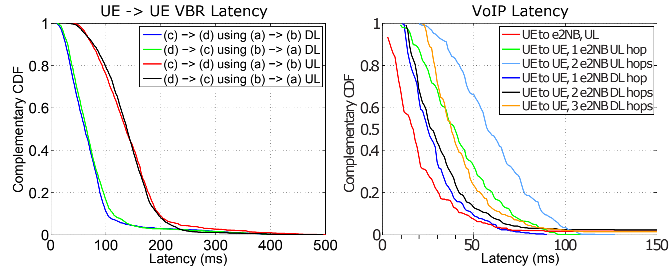


Fig. 7. Latency of Variable Bit Rate (VBR) flow and VoIP over multi-hop

satisfy the requirement. On the contrary, we still have some room left after three e2NB DL hops (five hops end-to-end).

V. Conclusion

In this paper we presented a new concept of enhanced LTE eNB, denoted as e2NB, that leverages the existing LTE components to support moving cells and dynamic meshing of base stations while preserving communication services for legacy UEs. The proposed e2NB brings several advantages over existing approaches in that it reuses the LTE air interface, works with only one LTE RF chain, and operates in a standalone mode. Experiments on basic topologies have been performed showing the feasibility of the approach. The results highlight the importance of the SF allocation on the packet latency and instantaneous goodput when using dynamic scheduling. Furthermore, results demonstrated that low latency multi-hop communication is achievable and that it can satisfy LTE QoS requirements.

Several future directions exist to improve the performances of the proposed e2NB, including the use of beam-forming, full duplex radios and/or different component carriers for e2NB communications.

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