# Phantom Cell Realization in LTE and its performance analysis

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*Abstract*— **In recent years, there has been a tremendous increase in the cellular traffic due to the availability of wide range of devices: smart phones, net-books, tablets, etc. The existing cellular networks will be unable to cater to the increasing demands in near future, thus we need technological enhancements in the cellular infrastructure to meet the ever increasing user requirements. Various approaches have been suggested to increase the existing cellular capacity and provide higher data rates, some of which include deployment of small cells under the coverage area of Macro cells, where a cell denotes the region covered by a particular base station (BS). However, since these small cells cover small regions there exists a significant handover signalling overhead. We suggest an approach where small cells, called Phantom cells, are deployed within the Macro cell coverage area, and the existing Macro BS functions as the centralized controller for all the Phantom BSs deployed within its range.**

**Phantom BSs act as a supplement to the existing Radio Access Network in the LTE infrastructure where it handles the data plane (D-plane) and Macro BSs handle the control plane (C-plane). This paper proposes the definitions of C-plane and D-plane, the modifications in the user equipment (UE) protocol stack which enable the concurrent operation with dual BSs (Phantom and Macro). Mechanisms are developed for the communication of a Phantom BS with a Macro BS over the new interface (X3 interface). NS-3 simulations were performed incorporating the designed architecture for Phantom based HetNets and a significant improvement in UE throughput is observed in comparision with legacy networks comprising of Macro BS.**

## I. INTRODUCTION

In the modern era, the use of smart phones, tablets and other new mobile devices which support a wide range of applications has increased immensely. Cisco VNI Mobile Forecast (2013) states that 79.2% mobile data usage is because of smart-phones and tablets, and mobile data is expected to register a tremendous growth of almost 11 times in the next four years, reaching 18 exa-bytes per month by 2018. The number of mobile users will rise significantly, to nearly 5 billion by 2018 (up from 4.1 billion in 2013). Also mobile video will account for 69% [1] of all mobile data by 2018, up from about 53% in 2013. Currently LTE networks are deployed worldwide providing higher efficiency and lower latency than the existing 2G/3G networks. But considering the above statistics, in the near future, even the existing 4G LTE networks would not be able to satisfy the demands. Thus we need to explore new ways to support the increasing capacity demand and desire for higher data rates. The existing approaches for indoor environments includes deployment of WiFi networks, Femtocells [2], [3] and in-building cells using distributed antenna systems (DAS). For outdoor environment, Femto cells [2] are also suitable as small cells. But outdoor scenarios have highly mobile users and these Femto cell networks thus incur a lot of handover overheads.

Our approach suggests deployment of small BSs called Phantom BSs (Phantom eNBs) working on high frequency band (3 GHz or more) as frequency band till 2.5 GHz is fully used as shown in Figure 1.

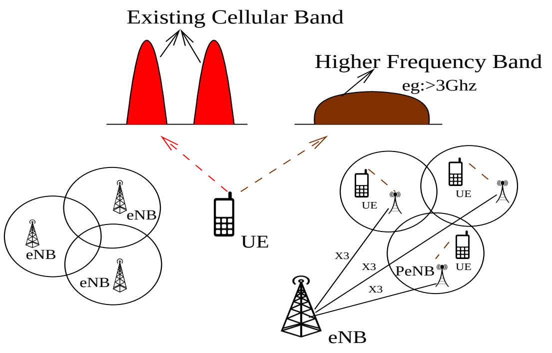

Figure 1. Frequency band and Network Distribution

In the Phantom cell network we have a centralized Macro eNB, which has multiple Phantom eNBs under its coverage area serving the user base. These Phantom eNBs are of smaller height as compared to Macro eNBs, and the coverage area under Phantom eNB, called as Phantom cells, is smaller as compared to the coverage area of Macro eNB called as Macro cells. But since it is operating at higher frequency, it would be capable of delivering higher data rates. In addition, there will be more cells in the network to serve the ever increasing user base. Phantom eNBs also overcome the limitations of Femto eNBs (mentioned earlier) because of a centralized Macro eNB controlling all Phantom BSs within its range.

Phantom cell concept is a capacity increasing solution, that would offer good support for mobility, benefitting from the existing LTE network. In the Phantom Cell concept, the C-plane/D-plane are split amongst Macro and Phantom BSs, as shown in Figure 2. Under this scenario, the control plane is supported by a continuous reliable coverage layer at lower frequency band i.e., the Macro eNBs while data plane is provided by Phantom eNBs at higher frequency band. The Co-operation of Phantom and Macro eNB relies on the X3 interface which is a dedicated point-to-point connection over an optical fiber [4] through which a Macro eNB controls the Phantom eNB. Since the user data goes through Phantom eNB which operates at a higher frequency band, the data rates are boosted.

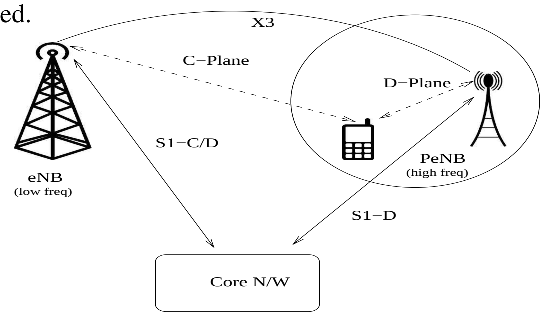

Figure 2. C-plane/D-plane Split among Macro and Phantom eNBs

### A. Advantages of Phantom Cell

1) Since Phantom and Macro eNBs operate at two different frequencies there is no interference experienced by the Macro eNB, and thus Phantom eNBs deployment does not adversely impact the functioning of large, legacy Macro cell networks.
2) No Re-arrangement of Macro eNBs is required due to inclusion of Phantom eNBs in the network.
3) We get the flexibility to turn the Phantom eNBs ON/OFF, depending upon the traffic levels. This is highly beneficial and could result in substantial energy savings [5].
4) Control signaling due to frequent handovers is significantly reduced because of the centralized architecture.
5) Deployment can be done according to the traffic requirement, in normal high traffic case (for eg: small parks) Phantom eNBs can be sparsely deployed and in super high traffic case (for eg: super markets, Techno parks, railway station) Phantom eNBs can be deployed densely to serve the needs.

In this paper an architecture for the realization of Phantom eNBs based heterogeneous network (HetNet) is discussed, describing communication mechanisms between Phantom eNB, Macro eNB and the user equipment (UE). Section II highlights some of the major architectural challenges associated with different network entities and there communication in this Phantom based HetNets. Section III explains about the modifications needed in the UE protocol stack, Initial cell acquisition and synchronization procedure if a UE gets connected with both Macro and Phantom eNB. Protocol stack of Phantom eNB, Random Access and Paging Mechanisms for Phantom based HetNets are also covered in Section III addressing the challenges described in previous section. Section IV describes some of the mobility scenarios illustrating the shift of data plane to and from between Phantom and Macro eNB. In Section V, we describe the experimental setup and analysis of results, followed by conclusions in Section VI.

## II. CONTROL AND DATA PLANE SPLIT:MAJOR CHALLENGES

Phantom eNBs, unlike conventional eNBs, will only send primary/secondary synchronization signals (PSS/SSS) and will not send cell specific reference signals, Master Information Block (MIB) and System Information Blocks (SIB) in the LTE frame structure. The Radio Resource Connection (RRC) procedures between a UE and the Phantom eNB such as channel establishment ($RRC_{Connected}$), channel release ($RRC_{Disconnected}$) and $RRC_{Idle}$ are all maintained by the Macro eNB on behalf of the Phantom eNB, with which the UE will get attached. Also, the authentication of the UE for attachment with the Phantom eNB is done by Macro eNB.

### A. Challenges:

Described below are some of the major challenges in obtaining and maintaining a concurrent parallel connection with the two eNBs in a Phantom based HetNet.

1) Since these two eNBs operate at different frequency band, the major challenge that arises is to facilitate the communication of a UE with both eNBs simultaneously. Switching to and fro, from one frequency band to another, is not practically feasible as it would result in decreased throughput and increased delay in communication with each of the two eNBs.
2) A UE has to time-synchronize with both the eNBs so as to facilitate proper data transfer.
3) Apart from regular control messages involved in channel establishment, handovers etc, mere data exchange between a UE and BS involves exchange of control messages such as acknowledgments, scheduling grants and scheduling decisions etc.Thus segregating and categorizing the parts of control plane and the data plane, and to specify a definitive boundary between them is a challenging aspect.
4) Mobility management of the UE: As the user is mobile, he/she may not necessarily be in the coverage of a Phantom eNB, and thus in such a situation, the Macro eNB has to take care of both control and data plane.

In order to make above provisions, we need to modify the UE protocol stack so that it is able to communicate in such a HetNet. Also the functionality in the protocol stack of Phantom eNB and Macro eNB needs to take into account the above structural changes and a mechanism to let them communicate over the X3 interface is needed as well. In the following subsections, we suggest step by step, the architecture of each of these different segments, and how the above challenges could be solved through them.

## III. PROTOCOL STACK OF PHANTOM UE, PHANTOM ENB AND INITIAL CELL ACQUISITION PROCEDURE

### A. Protocol Stack of Phantom UE(UE connected to both Macro and Phantom eNB)

In the current scenario, a UE is tuned into a certain frequency band/channel, typically of the 2.5GHz spectrum, for its operation and communication. But these HetNets, where Phantom eNBs, generally operate at 3GHz or more, demands UEs to be able to work at two different frequencies for transmission to, and reception from the Macro and Phantom eNBs simultaneously. In order to have this capability we propose addition of an extra radio (i.e UE_Phantom Physical Layer) at each UE as represented in Figure 3 along with the existing UE protocol stack. The new radio also interacts with the existing MAC and other higher layers in the traditional LTE-UE stack. In addition, all the above layers maintain the state information of whether the UE is in Phantom mode (where it is connected to Phantom eNB for data and Macro eNB for control) or in Macro mode (where everything goes through Macro eNB). Depending upon the topology and the mobility of the UEs, a UE may or may not be connected to Phantom eNBs. It is thus necessary to keep the state information available at the upper layers.

Now when a UE is in the Phantom mode, the data from higher layers would pass down the stack and would be sent through the new radio to the Phantom eNB. Similarly, any downlink data from Phantom eNB would go up the existing stack passing through the new radio. When user is connected to both the Phantom and Macro eNBs and has some data to be sent in the uplink, the MAC layer ensures that it uses the PUCCH (Physical Uplink Control Channel) of the new radio in order to request resources (scheduling grant) for transmitting data. Similarly, if there is a downlink data from Phantom eNB to the UE, UE would be informed through PDCCH (Physical Downlink Control Channel) of the new radio for receiving data through the PDSCH (Physical Downlink Shared Channel).

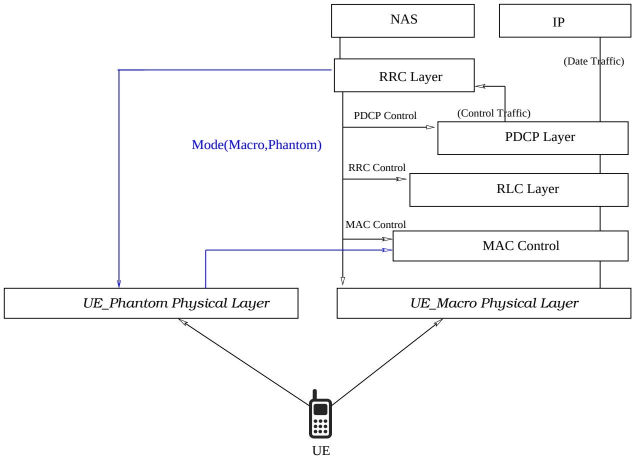

Figure 3. Protocol Stack of Phantom UE

### B. Initial Acquisition/Synchronization procedure with Phantom and Macro eNB

As soon as a UE (mobile device) is switched on, it performs a cell acquisition procedure so as to identify nearby cells to connect with and to get the configuration of the cell for communication purpose. Here UE tries to find PSS from both the Macro and Phantom eNBs (if any present in the vicinity), and thus gets the physical cell layer identity (PCID) of the two cells and also acquires the 5ms (sub-frame timing) of the two cells. In next step, UE finds SSS, and is thus able to get the cell identity group and frame timing of the cells. Author [4] suggests that there should be no PSS/SSS from Phantom eNB. One approach in this regard could be sending the PSS/SSS of Phantom eNB through Macro eNB, where Phantom would be sending the PSS/SSS information to Macro eNB through X3 interface. However, this would incur a lot of communication delay and is highly infeasible and an unscalable approach.

After receiving PSS/SSS, UE gets the MIB from the Macro eNB. However, there would be no MIB from Phantom eNB. Instead, the Phantom eNB communicates all MIB related information to Macro through the X3 interface. Traditionally, Macro eNB sends following information in the MIB:-

1) Downlink bandwidth of Macro.
2) System Frame Number.

Now since the Phantom eNBs will not be transmitting any MIBs, we have modified the MIB of the Macro eNB so as to include the downlink bandwidth of the Phantom eNB as well. Thus through MIB from Macro eNB, UE gets to know the downlink bandwidth of the Phantom. Similarly, there would be no SIBs from Phantom eNB. So the SIB-2 that we get from Macro which typically includes the uplink bandwidth of Macro eNB, would now also include the uplink bandwidth of Phantom eNB. Similarly, all the system information, including the configuration details present in SIB 1-9 coming from Macro eNB, now also includes the system information for Phantom eNBs, which a Phantom eNB passes to a Macro eNB through X3 interface.

If the signal strength from Macro eNB is higher than the Phantom eNB, then UE would be merely connected to the Macro eNB for both control and data transfer. However if UE gets a better signal strength from the Phantom eNB, then it would be attached to the Phantom eNB for data transfer, and the new radio will communicate with the Phantom eNB as explained in the previous section.

### C. Protocol Stack of Phantom eNB

Phantom eNBs provide high scalability by providing flexibility to network operators to gradually add capacity. Its deployment can be done according to the need and may not necessarily be uniform everywhere. The layers in the protocol stack of Phantom eNB would be the same but with some modifications in their functionality. A Phantom eNB is connected just to the P-GW and there is no connectivity with the MME (Mobility Management Entity) in the core network as shown in Figure 2. A user in any scenario would be connected to the Macro eNB and thus all NAS (Non-Access Stratum) messages for authentication of the UE would go to Macro eNB. Now if a UE is connected to Phantom eNB for data transfer then Macro eNB would share the authentication related information of the UE with the Phantom eNB through the X3 interface. All the signaling radio bearers (SRB)which are the radio bearers for transmission of RRC and NAS messages are sent by the Macro eNB. Phantom_ NAS as shown in Figure 4 would merely store the information regarding the authentication of UE, and there is no message exchange between MME and the UE regarding the authentication. Likewise, Phantom_ RRC layers as shown in Figure 4 keeps information regarding establishment of RRC context. The following sub-sections specifies two main mechanisms which are performed by Macro eNB on behalf of the Phantom eNB to aid the data transfer procedure.

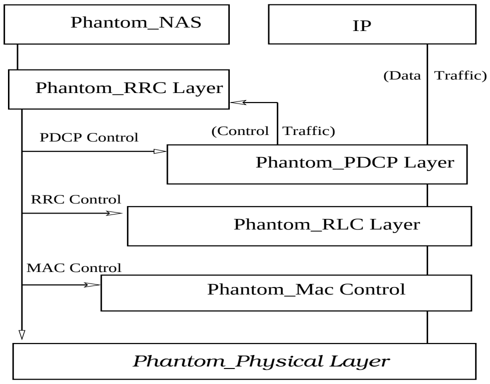

Figure 4. Protocol stack of Phantom eNB

1) Random Access and RRC Connection Set Up: In this Phantom based HetNet, a UE has parallel connectivity with two eNBs, and thus random access and RRC connection set up mechanisms take place differently. A Macro eNB maintains the information that whether a UE is connected to it just for control or control and data transfer both. Now when a UE performs random access by selecting one of the preambles and transmitting it over PRACH, the request arrives at the Macro eNB. Since the Macro eNB has the information of dual connectivity of UE, it passes this random access request to the appropriate Phantom eNB, with which the UE is connected, through X3 interface as shown in Figure 5. Phantom eNB then assigns a temporary C-RNTI and also determines the timing advance for the UE through the location information of the UE passed by Macro eNB. This response is again passed back to the Macro eNB which informs the UE through DL-SCH.

   However, Macro eNB assigns resources to the UE for transmitting RRC connection request in the next step. In the third step, UE sends RRC connection request via UL-SCH through resources assigned in the previous step. Phantom eNB then sends contention resolution to the UE via Macro eNB (Figure 5). Note that from first step multiple UEs may be performing simultaneous random access using the same preamble sequence which would thus be getting same temporary identifier in second step. In the fourth step, UE compares the identity in the message with the identity received in second step. A terminal which finds the match, has completed the random access process successfully and the data transfer would take place via Phantom eNB, through the new radio in the UE. One advantage of having Phantom eNB and redirecting the Random Access request to Phantom eNB by Macro eNB is that each Phantom/Macro eNB has its own separate collision domain, thus reducing the probability of collisions.

   Consider a scenario in which a UE is connected merely to a Macro eNB and an other UE is connected to both Phantom and Macro eNB. Assume that they happen to pick up the same preamble during their random access attempt. Both UEs could still successfully transmit the data as preamble of UE connected to Macro eNB would go to it as usual while the preamble of the UE connected to both eNBs would go to Phantom eNB and thus no collision even on picking up the same preamble.

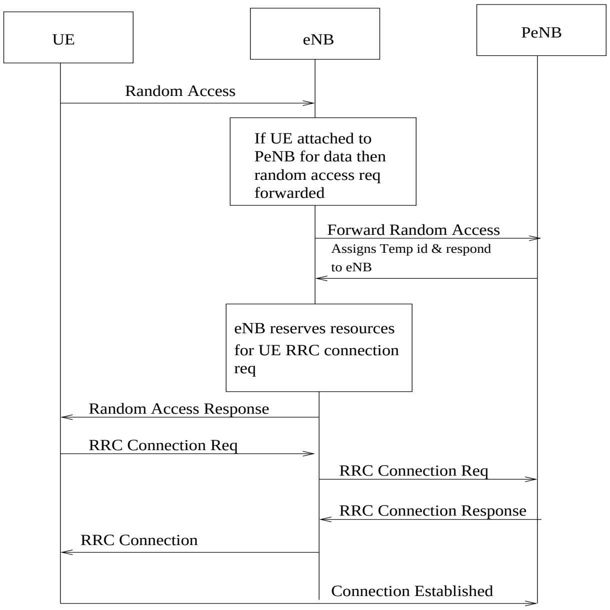

Figure 5. Flow Diagram for Random Access in Phantom based HetNets

2) PAGING: Paging is a network initiated connection setup mechanism when there is some downlink data to be sent to the UE. It is the mechanism through which the network informs a UE of some incoming data. In LTE, S-GW gets the data for a UE, which then informs MME about the incoming data. Now since only the Macro eNB is connected to the MME, MME informs all Macro eNBs under its tracking area about the paging message. Macro eNB configures at which sub-frames a UE should wake up and perform paging. A UE constantly wakes up at this predefined time intervals to monitor the paging information from the network. Phantom eNB does not send any of the paging messages as it is not connected to the MME. A UE searches for P-RNTI in the paging message received through PDCCH of the existing physical layer and not of the new radio (referred in previous section). UE then tries to decode PDSCH from the information in PDCCH and looks for the identity information (P-RNTI) included in the paging message. If UE finds it to be a match with its own identity then it triggers random access procedure followed by establishment of the RRC connection setup. Thus we can conclude that a Macro eNB aids the data transfer process by performing paging and RRC connection/Re-connection establishment procedures while data movement takes place between the new radio of the UE and the Phantom eNB.

Phantom and Macro eNBs protocol stack thus needs to have mechanisms to communicate with each other over the X3 interface for the above mentioned procedures to take place.

## IV. HANDOVER SCENARIOS IN PHANTOM BASED HETNETS

In this Phantom based HetNets, we have an advantage of having a centralized controller (Macro eNBs) which has complete information of the topology and configuration of all Phantom BSs under its coverage area. Also there would be a substantial reduction in signaling messages being exchanged during handovers because of Macro BS controlling the entire handover procedure. In this context the following mobility scenarios could arise :-

### *A. Macro eNB to Phantom eNB Handover*

User is currently connected to the Macro eNB for both control and data transfer when it is at location X as shown in Figure 6. Macro eNB advertises location of Phantom eNBs under its coverage area through SIBs and when enters into these location its second radio gets activated. Now in Figure 6 when UE is at location Y its second radio is activated since it is in the coverage area of a Phantom eNB, and also it starts receiving good signal strength from that particular Phantom eNB. UE reports about this to the Macro eNB. Macro eNB acts as a controller which decides about the attachment of the UE to Phantom eNB based on the current load of that Phantom eNB and the quality of signal UE is receiving from that Phantom eNB. If it decides to attach UE to Phantom eNB, it then instructs the appropriate Phantom eNB through X3 interface to handle the new user and also informs the user, which then starts communicating with the Phantom eNB through the new radio. Hence, the user would now get attached to the Phantom eNB for the data transfer, and to the Macro eNB for the exchange of control messages as shown in Figure 6.

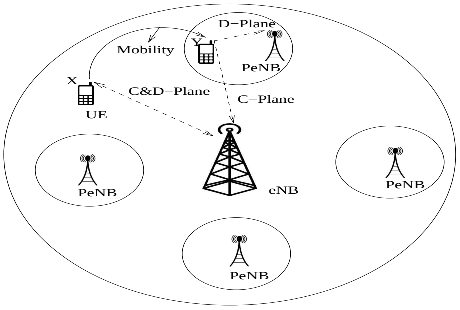

Figure 6. Handover in Phantom Based HetNets.

### *B. Phantom eNB to Macro eNB Handover*

This scenario is exactly the reverse of previous one where a UE moves out of the coverage area of the Phantom eNB and the Macro decides to handle the UE for both control and data transfer. It instructs the UE, to disable the new radio, and the Phantom eNB, to release the resources currently allocated to the UE.

### *C. Phantom eNB to Phantom eNB Handover*

Under this scenario, UE moves from the coverage area of one Phantom eNB to another Phantom eNB.

## V. PERFORMANCE EVALUATION

Simulations are performed in NS-3.19 simulator to realize the architecture and mechanisms proposed in the previous sections. Assumptions taken are in accordance with the latest 3GPP Release. Various additional functionality are added on top of the current support provided by the simulator for LTE.

### *A. Experimental Set Up*

*1) Static Scenario:* We have considered three different network configurations for the simulation study. In all these configurations UEs are kept static.

**Configuration (a):** One Macro eNB is deployed at the position (0,0,0) and 5 UEs are placed on both sides of the Macro eNB at positions (20,i,0) and (-20,i,0) where i = j * 45 [ $0 \leq j \leq 4$ ]. No Phantom eNB are deployed in this scenario.

**Configuration (b):** One Macro eNB is deployed at the position (0,0,0) and along with that Phantom eNBs are placed on both sides of the Macro eNB at positions (15,i,0) and (-15,i,0) where i = j * 45 [ $0 \leq j \leq 4$ ]. UEs were placed at similar coordinates as in the case (a).

**Configuration (c):** It has similar configuration as (b) with Phantom eNBs being replaced by Femto eNBs.

TCP flows are installed over each of the UEs to transfer 1 MB of data from the UE to a Remote Host connected over the Internet and vice versa. Consider for example, if we have 2 UEs, then TCP flows are installed between each of the UE and the Remote Host in both uplink and downlink direction (Figure 10).

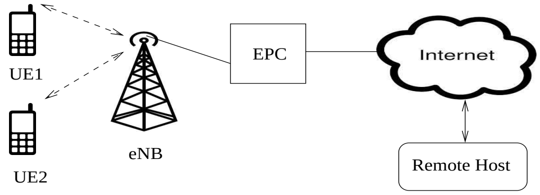

Figure 10. TCP Flow Between UEs

*2) Mobility Scenario:* Simulation experiments are performed for the following network configurations:

**Configuration (a):** Only a single Macro eNB is deployed

**Configuration (b):** Four Phantom eNBs are deployed at a distance of 900m from a Macro eNB to realize the scenario as shown in Figure 6.

**Configuration (c):** Four Femto eNBs are deployed at similar locations as Phantom eNBs in the previous case.

Each of the these three configurations consists of 11 UEs, 10 of which are static and are placed at locations as in static configurations discussed above. A single UE is made to rotate a 360° circle around Macro eNB with velocities 1m/s, 3m/s, 5m/s, 10m/s for different runs. TCP flows are installed from UEs to a Remote Host on the Internet and vice versa. The initial position is kept such that when there are Phantom/Femto eNBs deployed, UE gets into the coverage area of these eNBs.

### *B. Metrics Considered*

Objective is to obtain an improvement in the capacity and throughput in these HetNets of Macro and Phantom eNBs. Thus we compare the throughput, delay and jitter values

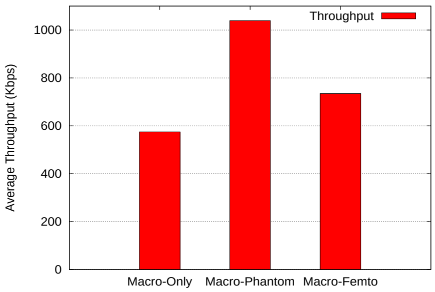

Fig. 7. Throughput Comparison of configurations in Static Scenario

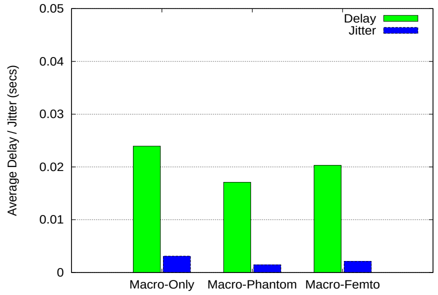

Fig. 8. Delay and Jitter Comparison of configurations in Static Scenario

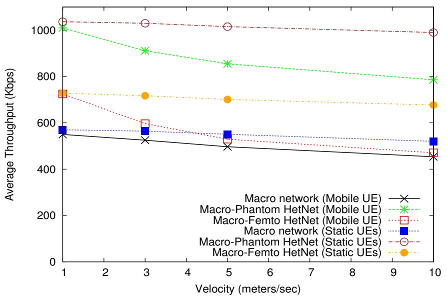

Fig. 9. Throughput Comparison of configurations in Mobility Scenario

TABLE I
NS-3 SIMULATION PARAMETERS

| **Parameters** | **Values** |
|---|---|
| Operating Freq. of Macro eNB | 0.7 GHz |
| Operating Freq. of Phantom eNB | 2.1 GHz |
| Building dimensions | 4m × 4m × 20m |
| Macro eNB height | 30m |
| Phantom eNB height | 5m |
| Macro and Phantom/Femto transmit power | 46 dbm and 20 dbm |
| UE maximum transmit power | 0.2W |
| LTE Mode | FDD |
| System Bandwidth for eNBs | 5MHz |
| Simulation Time | 100 secs |

obtained while UE is connected to Phantom eNB with the values obtained when UE is connected to Macro/Femto eNB.

### *C. Performance Results*

*1) Static Scenario:* In Configuration (a) for the static scenario in the experimental set up, UEs get connected to the Macro eNB. However in Configuration (b), since UEs get better signal strength from Phantom eNBs, they get attached to the appropriate Phantom eNBs for data transfer and Macro eNB for control. Average of the throughput, delay and jitter values obtained at UEs was calculated for all the three configurations mentioned in static scenario. Figures 7 and 8 illustrate the difference in the value of these metrics among the legacy Macro network, Macro-Phantom HetNet and Macro-Femto HetNet. 80% increase in throughput is observed when UEs are attached to Phantom eNB for data transfer as it operates on a separate frequency band. Also when UEs are far away from the Macro eNB they would be transmitting with low modulation schemes like QPSK. However if there is a Phantom eNB nearby and a UE gets connected to it, UE has to be close enough to Phantom eNB as it has small coverage area. Thus UE would be able to pump data using higher modulation schemes like 16-QAM and 64-QAM. Also since there are less signaling messages that are exchanged between UE and the Phantom eNB before and during data transfer, which are taken care of by Macro eNB, contributes further to an increase in throughput and decrease in delay and jitter values. Similarly for traditional Femto based HetNets we observe a lower throughput and higher delay/jitter as compared to Phantom based HetNets.

*2) Mobility Scenario:* Throughput values are higher for Phantom and Femto based HetNets in comparison to mere Macro eNB network. Figure 9 depicts the average throughput for 10 static UEs and throughput of one mobile UE for each of the Macro, Macro-Phantom HetNet and Macro-Femto HetNet at different velocities. As Phantom/Femto eNBs form small cells, a user is typically closer to them and thus higher modulation schemes are utilized. There is a decline in throughput value of mobile UE for all the configurations in the mobility scenario as velocity of the mobile UE increases. A significant drop is observed in throughput in case of Femto based HetNets while UE is moving with 10m/s in comparision to static UEs, as it incurs handover overheads which is initiated by Femto eNB. Throughput drop in Phantom based HetNets is smaller than Femto based HetNets because of the centralized architecture and the Macro eNB controlling the handover mechanism.

## VI. CONCLUSION

In this paper, we designed mechanisms to split the control and data plane among Macro and Phantom eNBs which facilitates higher throughput and less overheads in terms of handover. Architectural changes in the UE protocol stack were made to enable communication at dual bands. Exchange of information between Phantom and Macro eNB over the X3 interface is facilitated. In future, we plan to move more of the control messages to the Macro eNB with bare minimum control data to be handled by the Phantom eNB.

## ACKNOWLEDGMENT

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