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Energy and Spectrum efficient Multimedia delivery services for LTE-A Heterogeneous Networks Using Random Network Coding

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ABSTRACT

Background: The use of high performance large screen smart phones is attracting more users towards the internet access day by day. Due to this, the demand of high data rates also increases rapidly. Since 2011, the traffic has increased more than 70% accounting for mobile video services and predicted to have more increase within 2016. 3GPP proposal for fourth generation (4G) technology provided the solution named Long Term Evolution (LTE) and LTE-Advanced technology, which provided very high data rates but still failed to meet the requirements. Among various layers of LTE-A system, MAC layer is the one which consumes 60% of total power when compared to other layers. In this layer, 25% of the total throughput is just used for signaling and overhead messages. This is due to the existing HARQ scheme in MAC layer. In this paper we address the issue by replacing Hybrid Automatic Repeat Request (HARQ) with Random Network Coding (RNC) in MAC Layer.**Objective:** In the proposed MAC-RNC scheme, acknowledgment message overheads are reduced, to result in reduced power consumption. The results are evaluated and compared with the existing MAC-HARQ in terms of various parameters such as SNR, BER, Throughput and Power. The deployment of HETNETs also has been considered for the increased network coverage along the edge of the network. The simulation tool used is MATLAB R2014a.**Results:**The results were simulated using MATLAB and the parameters such as throughput, SNR, BER and power has been derived successfully.**Conclusion:**A novel RNC method in MAC layer promises the best use of total energy consumptions and throughput and performance.

INTRODUCTION

LTE (Long Term Evolution) is a new high performance air interface for cellular mobile communication systems developed by the 3rd Generation Partnership Project (3GPP), collaboration between groups of telecommunications associations. LTE represents a major advance in cellular technology. It is the next step in a continuous move to wider bandwidths and higher data rates. LTE is expected to be the next major standard in mobile broadband technology that promises to enhance the delivery of mobile broadband services through a combination of very high transmission speeds, more flexible and efficient use of spectrum, and reduced packet latency. To fulfil its ambitious requirements for spectral efficiency and high data rate, LTE has selected Orthogonal Frequency Division Multiple Access (OFDMA) as the multiple access scheme for uplink. OFDMA is an extension of OFDM (Orthogonal Frequency Division Multiplexing) to accommodate multiple users. OFDM, being a multi-carrier modulation method, offers a number of advantages including high data rate,

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robustness against interference in multipath fading channels, and simple implementation methods. LTE works on two different types of air interfaces (radio links), one is downlink (from Base Station to User Equipment), and one is uplink (from User Equipment to Base Station). By using different types of interfaces for the downlink and uplink, LTE utilizes the optimal way to do wireless connections in both of the ways which makes a better optimized network and better battery life on LTE devices.

LTE was the 9th release of 3GPP Organisation, which had some disadvantages in it. Hence it upgraded LTE with additional features in its 10th release and named it as LTE-Advanced. LTE-Advanced showed increased performance when compared to LTE. LTE-A provided thrice the data rate of LTE and also covers Bandwidth of about 20MHz - 70MHz, whereas LTE has a Bandwidth of about 1.4MHz- 15MHz. Another main aim of LTE-A was to provide better performance in cell edges, for which it introduced Heterogeneous Network (HetNet) to increase the signal strength in the cell edges and in order to reduce the power consumed by the user equipment in the cell edges. The major disadvantage of both LTE and LTE-A in common is, 25% of the total throughput is used for the signaling and overhead messages.

In recent years, the use of the high performance smartphones is increasing abruptly, which also attracts more users towards the internet access day by day. This results in more demand for mobile data rates. Inspite of having even much advancements when compared to LTE, even the existing LTE-A systems fall short to provide such high data rates. To overcome this disadvantage different layers of the communication system are being examined by scholars all over the world. One major cause is that the MAC Layer uses 25% of the throughput for signaling and overhead messages. Hence the major motivation of the work is to reduce the signaling and overhead messages in the MAC layer efficiently without affecting the advantages of LTE-A network. It also concentrates on the reduction of energy consumption by both Base Station and the User Equipment.

In this paper, we consider random network coding (RNC) as a simple and flexible solution compatible with deployment of HetNets. We present a detailed study of a MAC layer RNC-based Protocol (MAC-RNC) for reduced power consumption and HetNets layout. It provides a qualitative step forward from the high-level protocol presentation towards the detailed description and evaluation of the MAC-RNC protocol that includes intricate details across the LTE-A protocol stack. In other words, this work intends to bridge the gap between the idea of using RNC as a replacement for HARQ in 4G wireless cellular networks and a detailed framework for MAC-RNC protocol realization in a specific LTE-A HetNet environment.

The RNC-MAC protocol is evaluated against the existing HARQ-MAC protocol in various LTE-A HetNet layouts with the parameters such as throughput, SNR, BER and Power. Our results demonstrate that the proposed MAC-RNC protocol provides the efficiency and flexibility required for future LTE-A communication.

MATERIALS AND METHODS

Hybrid Automatic Repeat Request In Mac-Layer:

Hybrid Automatic Repeat Request:

Hybrid Automatic Repeat Request (HARQ) is the mechanism which is used in the MAC Layer of the present LTE communication systems. Every Smart device wants to receive information quickly and free of error. But with complex mobile radio systems and an increasingly noisy environment, this isn’t always possible. So if the data is not received at the first time, it is still expected to arriveatleast with a minimal delay. Network providers plan to rectify these drawbacks by minimising resources. The 3GPP Long Term Evolution Advanced (LTE-A) standard takes advantage of the hybrid automatic repeat request (HARQ) process in addition to adaptive coding and modulation (AMC). This is critical to minimize the turnaround time and maximize the data throughput of the system.

The telecommunications industry has used the Automatic Repeat Request (ARQ) layer 2 protocol for many years to ensure that data is sent reliably from one node to another in LTE systems. In regular ARQ, error-detecting (ED) codes such as cyclical redundancy checking (CRC) and a sliding window are used to identify when an error has occurred in a transmission. If errors are detected, the destination requests a retransmission from the source. During good radio conditions, ARQ can be considered very efficient, as no additional forward error correction (FEC) bits are added to the basic data to be transmitted. Yet bandwidth efficiency will suffer significantly in poor channel conditions due to excessive retransmissions. Hybrid ARQ performs better than regular ARQ in poor signal conditions, but in its simplest form, this comes at the expense of significantly lower throughput in good signal conditions. There is typically a signal quality crossover point below which simple hybrid ARQ is most efficient and above which basic ARQ is the best solution.

HARQ Process:

HARQ uses a stop and wait protocol. When a transmission has been made, the transmitting entity stops and waits until it receives an acknowledgment (ACK) or negative acknowledgement (NACK) back from the destination before transmitting the next block of data or retransmitting the same data block. In either case (ACK or NACK), the transmitting entity is required to schedule and process the next transmission within a specific time period.

For LTE frequency-division duplex (FDD) on the uplink, this time has been set to eight 1-ms subframes. Since it only takes one subframe to transmit the data, this result in seven sub frames of unutilized bandwidth. To fully utilize this bandwidth, LTE uses multiple HARQ parallel processes offset in time from each other. Each process transmits a block of data. By the time its next transmission allocation arrives, it will have already received the ACK or NACK from the receiving entity and created the next packet for (re)transmission.

In addition to that, Fig. 1 represents the MAC-HARQ protocol architecture with a detailed representation of the process carried out in the MAC layer. In the MAC-HARQ protocol architecture in which the RLC PDU in the RLC Layer is further forwarded to the MAC Layer which takes the form of MAC PDU. A complete RLC PDU contains 8 MAC PDUs in it, which represent a complete packet. For every individual MAC PDU, the HARQ sends one acknowledgement. The nature of the acknowledgement may be Positive ACK or Negative ACK, depends on the received MAC PDU. HARQ keeps retransmitting of ACK messages until the whole MAC PDUs are received at the MAC Layer to form a complete Packet.

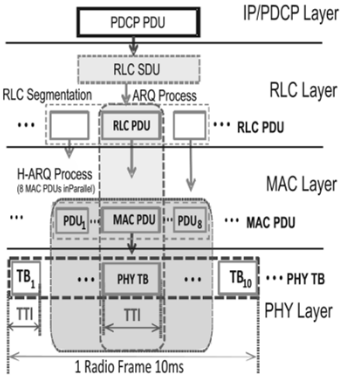

Fig. 1: MAC HARQ Protocol architecture

Due to the repeated retransmission of a single MAC PDU, delays the delivery of the whole IP packet. Finally, in multi-hop scenarios, the MAC-HARQ protocol is unable to exploit possible network coding gains and introduces additional delays for sequential delivery of each MAC PDU over consecutive hops.

Disadvantages of HARQ:

The existing MAC layer hybrid automatic repeat request protocol performs well over point-to-point wireless links but for the future multi-point and multi-hop topologies, the performance are limited. This is because the MAC-HARQ contains high signaling overhead messages for Positive Acknowledgment or Negative acknowledgement. The disadvantages of HARQ scheme are, it is complex, it is not suitable for Multi-hop deployments and Multimedia Streaming, also it does not provide energy efficiency in User Equipment, and M2M communications.

Random Network Coding:

The first idea of the Network coding was implemented in the Network Layer. It proposes that Network coding is a coding at the node of a network with error-free links. It also states that, here the data is divided into packets and network coding is applied to the contents of packets. This provided the base idea in implementing Random Network Coding at MAC layer. Further the Network coding was upgraded with fine corrections and provided to be Random Network Coding.

Present practical communication networks such as the Internet; the information delivery is performed by routing. A promising generalization of routing is offered by implementing Random Network Coding. The potential advantages of network coding over routing include resource (bandwidth and power) efficiency, computational efficiency, and robustness to network dynamics.

RNC in network layer:

The butterfly network in Fig. 2 is often used to illustrate how linear network coding can outperform routing. Two source nodes (at the top of the picture) have information A and B that must be transmitted to the two destination nodes (at the bottom), both A and B. Each edge can carry only a single value (we can think of an edge transmitting a bit in each time slot).

If only routing were allowed, then the central link would be only able to carry A or B, but not both. Suppose we send A through the center; then the left destination would receive A twice and not know B at all. Sending B poses a similar problem for the right destination. We say that routing is insufficient because no routing scheme can transmit both A and B simultaneously to both destinations.

Using a simple code, as shown, A and B can be transmitted to both destinations simultaneously by sending the sum of the symbols through the center – in other words, we encode A and B using the formula "A+B". The left destination receives A and A + B, and can calculate B by subtracting the two values. Similarly, the right destination will receive B and A + B, and will also be able to determine both A and B.

A similar concept has been used to encode stereophonic sound, where there is a "left" signal and a "right" signal. The two analog signals are "added" together, and the "sum" is subsequently used to recover the original signals.

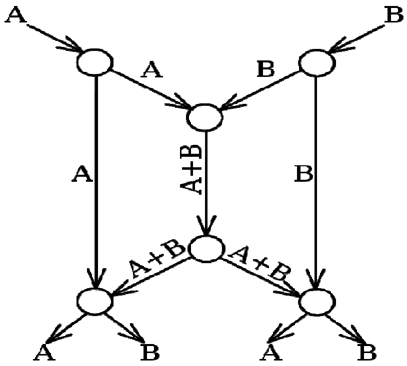

Fig. 2: Butterfly network

Implementation Of Rnc In Mac Layer:

Random Network Coding in MAC layer is as similar to the RNC in Network Layer. The only difference is that instead of Combining the packets at the node, the MAC PDUs are combined at the MAC Layer and forwarded to the Physical Layer.

As the combination provides the much protection against the signal degradation, there is no necessity of unwanted Signalling and Overhead messages. The same mechanism which was carried out in Network Layer was followed here in the MAC layer. The work intends to bridge the gap between the idea of using RNC as a replacement for HARQ in 4G wireless cellular networks and a detailed framework for MAC-RNC protocol realization in a specific LTE-A environment. The RNC-MAC protocol is evaluated against the existing HARQ-MAC protocol in various LTE-A E-UTRAN layouts.

A simple approach to perform packet combining in source/network nodes that results in efficient rateless/network coding solution is by applying RNC. Let $x = \{x_1, x_2,...,x_K\}$ be a source message containing K equal-length source symbols of length l bits. By applying RNC over the message x, a transmitter, e.g., an LTE base station (eNB), can ratelessly produce an arbitrary number of encoded symbols where each symbol c is of the same length l bits as the source symbols and represents their random linear combination

$$c = \sum_{i=1}^{K} gi \ . \ \ xi$$

with coefficients g_i randomly selected from a finite field GF(2^q). A receiver, e.g., a user equipment (UE), can decode x as soon as it collects any set of K linearly independent encoded symbols $c = \{c_1,c_2,...,c_K\}$ using the Gaussian Elimination (GE) decoder. To perform GE inversion, for each encoded symbol c_i, the receiver needs the corresponding global encoding vector $g_i = \{g_{i,1}, g_{i,2},..., g_{i,K}\}$. In this work, due to short symbol lengths l, instead of attaching g_i as a header information to c_i, we assume that the transmitter-receiver pair make use of synchronized random number generators (RNG) to (re)create the coefficients from short RNG seeds exchanged in packet headers. The GE decoding complexity scales as O (K3) which introduces complexity limitations on the length K of the source message to up to few hundreds of source symbols. To parallelize the decoding and reception process, the UE may apply progressive GE decoding thus completing the decoding as soon as the final linearly independent encoded symbol is received. This incurs minimum delay on the feedback message (ACK) transmitted by the UE to the (set of) transmitting node(s) to acknowledge the source message reception.

MAC-RNC Protocol Architecture:

To integrate the MAC RNC protocol within the LTE-A protocol stack, it is needed to define a suitable position for MAC-RNC processing. Due to high dynamics of packet (PDU) lengths at lower LTE-A layers, flexible definition of the source message *x* containing *K* source symbols and the source symbol size *l* is critical for efficient MAC-RNC design. The MAC PDU cannot be defined as the source message, due to its large variability in size. Indeed, the MAC PDU size depends on the UE channel conditions (CQI) and the UE resource allocation (N_{RBP}), and for bad channel conditions and the smallest resource allocation (LTE Category 1 User: N_{RBP} =6), the MAC PDU size can be as low as 48 bytes. If the source/encoded symbol size is set to l =4 N_{RBP} bytes (l = 32N_{RBP} bits), each MAC PDU could transfer n encoded symbols.

Thus we adopt the MAC PDU as a variable capacity encoded symbol container, rather than the source message itself. Note that the symbol size *l* is defined to scale with N_{RBP} in order to make the proposed MAC-RNC scheme (i.e., the MAC PDU capacity n) independent of the LTE-A user category (N_{RBP}). Moving up to the RLC layer, which has built-in segmentation/concatenation functionality, it recognize a suitable place where the source message *x* could be defined. Namely, instead of segmenting/concatenating PDCP/IP packets to match the upcoming PHY TB size, in the proposed MAC-RNC solution, the RLC layer should produce RLC PDUs suitable for MAC-RNC processing. Fixing the symbol size to *l* =4 NRBP bytes, the source message size is K ·4N_{RBP} bytes, where suitable values of K could depend on application scenario and its range. Thus the RLC layer encapsulates one or more PDCP/IP packets into the RLC PDU to match the desired *K* value. The RLC PDU is then forwarded to the MAC layer, where in the form of a MAC service data unit (SDU), it represents the source message *x* suitable for MAC-RNC processing. Finally, the core of the MAC-RNC protocol is integrated as the MAC-RNC sublayer positioned as an upper MAC sublayer (Fig. 3.6). The MAC-RNC sublayer is simply a RNC encoder: it divides the received MAC PDU into K equal-length source symbols from which a stream of encoded symbols is produced. A group of n = n(CQI) encoded symbols is placed into a MAC PDU to fit the upcoming PHY TB size reported by the MAC scheduler. The resulting MAC PDU is transmitted by PHY.

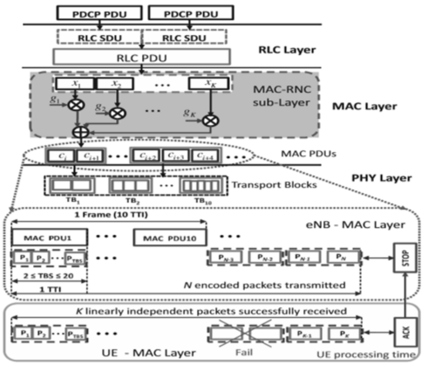

Fig. 3: MAC-RNC Protocol architecture

The MAC-RNC sublayer produces encoded symbols in a rateless fashion and fills variable size MAC-PDU containers based on the upcoming PHY TB sizes provided by the MAC scheduler (Fig. 3). In order to recover the global encoding vector *g* for each encoded symbol, an RNG seed of the first encoded symbol within the MAC PDU is transmitted, while RNG seeds for remaining encoded symbols in the MAC PDU are derived incrementally from the initial RNG seed, as in the Raptor solution in 3GPP Multimedia Broadcast/Multicast Service (MBMS). The RNG seed is robustly transmitted within the DL control channel (PDCCH) that delivers signaling data along the PHY TB data on a per TTI basis.

Advantage of MAC-RNC over MAC-HARQ:

Implementing MAC RNC over MAC HARQ provides various advantages for the 3GPP LTE-A Wireless Communication. MAC RNC provides less Signaling and Overhead messages when compared to MAC-HARQ. The state of the art MAC-RNC technique boosts the throughput of the LTE-A communication. This is because the bits used for overhead messages are used for sending the data bits. In proposed method, the delay is reduced by sending only one ACK message for a whole packet. In MAC-RNC the frequent ACK signaling is reduced and the power consumption at both the User Equipment and Base Station is highly reduced. The complexity of the MAC-HARQ is also reduced by implementing the MAC-RNC. By reducing the ACK, it is possible for LTE-A MAC-RNC to carry out multimedia delivery services more efficiently than the service provided by LTE using MAC-HARQ

Implementing MAC RNC over Heterogeneous Network:

To increase capacity and improve service quality, LTE-A radically shifts the classical macro-cellular LTE architecture, shown in Fig. 4 in favour of a so called Heterogeneous Networks (HetNets) architecture of Fig. 3.8 by introducing closer-to-user small cells on top of the macro-cellular layout. HetNets promise to address capacity requirements and provide more predictable wireless channel conditions even in the cell edges.

However, ongoing research on cooperation and coordination for upcoming LTE-A evolved universal terrestrial radio access network (EUTRAN) development is mostly focused on physical layer (PHY) techniques, while the upper layers remain largely intact. Hence to overcome that issue the MAC-RNC is combined with the HetNets to form a promising communication all over the cell.

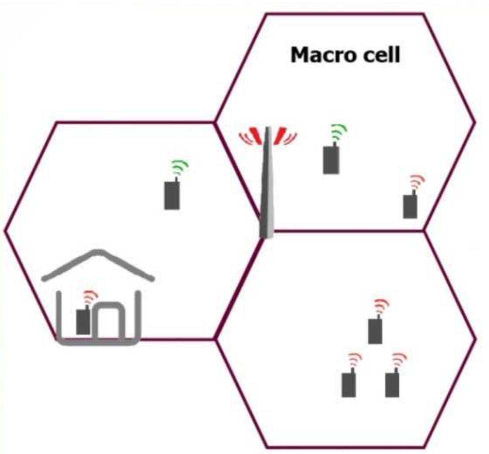

Fig. 4: Traditional Macro cell

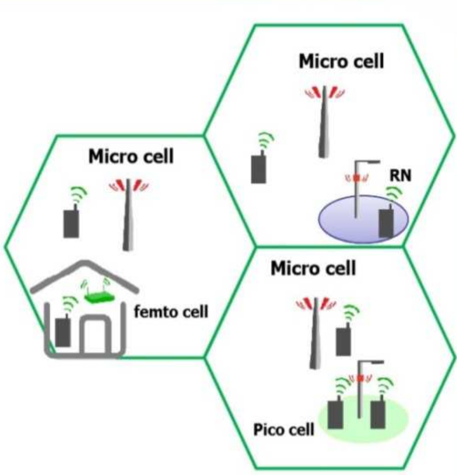

Fig. 5: LTE-A Heterogeneous Network architecture

Fig. 5 illustrates a generic HetNets E-UTRAN architecture consisting of macro eNBs adjoined with additional small cells such as micro/picoeNBs and possible deployment of relay nodes (RNs) attached to macro eNBs. The task of the LTE-A E-UTRAN is to deliver IP packets from the Base Station to the UE even at its cell edges. As described above, HetNets in MAC-HARQ, reduces independent transmissions of MAC PDUs containing groups of the original IP packets after concatenation at the RLC layer. Clearly, extension of the MAC-HARQ protocol to the multi-point transmission scenario would require significant coordination effort by MAC-HARQ processes in different transmission points in order to maintain seamless transmission of different IP packet parts. Furthermore, the IP packet is delivered to the UE only after MAC PDUs carrying all of its parts are delivered; thus repeated retransmission of a single MAC PDU delays the delivery of the whole IP packet. Finally, in multi-hop scenarios, the MAC-HARQ protocol is unable to exploit possible network coding gains and introduces additional delays for sequential delivery of each MAC PDU over consecutive hops. In contrast, in the following, we describe a simple and flexible MAC-RNC protocol able to efficiently deliver IP packets over the upcoming LTE-A HetNets architecture.

RESULTS AND DISCUSSION

System Model:

For simulation, uplink parameters specified in 3GPP LTE Release 8 are referred. A block transmission with each data block consisting of 100 samples and a total of 96 blocks are considered. The data blocks are encoded using a convolutional encoder with a constraint length 7 and standard generator polynomial. 16-QAM is used as the modulation scheme and the numbers of subcarriers considered are 128. FFT window size is fixed at 64 that gives a spreading factor Q=2 given by the relation Q= M/N where M is the total number of subcarriers used and N is the FFT window size.16 extra bits are used as cyclic extension for each data block. For Random Network coding, the Logical XOR is used at the MAC Layer. For categorizing the MAC PDUs the respective MAC address of individual MAC PDUs are mapped. The system takes a comparison of MAC-HARQ with the same simulation parameters. The system is simulated using MATLAB tool and the simulation parameters are listed in Table.1.

Scenario Considered for Simulation:

The Scenario considered for the simulation is a LTE-A Heterogeneous Network with the MAC Layer in a primary downlink. The User Equipment at different distance from the Base station towards the Relay nodes is considered for better understanding and performance analysis.

Table 1: Simulation Parameters

Parameter	Value
Coding used	Random Network Coding
Modulation	16 QAM
Channel	Rayleigh
System Bandwidth	20 MHz
No. of subcarriers	128
Carrier Frequency	2.0 GHz
Decoder	Gaussian decoder
System Layout	Macro Cell With a Relay Node
Traffic Model	Downlink
ACK Signaling	8 for HARQ 1 for RNC
Pathloss	20 dB

Performance Evaluation of LTE Heterogeneous NetworkUsing MAC-RNC:

The SNR at the UE, placed at a distance d from the eNB, is calculated as:

$$SNR(d)=P_{TX} + G_{TX} + G_{RX} - N_{RX} - I - S(d) - PL(d) - PNL$$

where P_{TX} is the macro/small eNB or RN transmission power (per cell sector); G_{TX} and G_{RX} are the macro/small eNB or RN and the UE antenna gains; I is the ICI power from all the interfering macro/small eNBs or RNs at the position of the observed UE; PNL is the wall penetration loss for signals received at indoor UEs; and finally, S and PL are the shadowing loss and the pathloss in dB measured at different UE positions using shadowing variances and pathloss models as given in Table 1. Based on the average SNR value at the UE, we establish corresponding FSMC-based PHY TB packet-level channel models for all wireless links active during the simulation experiment.

Here the Signal-to-noise ratio is a measure that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels.

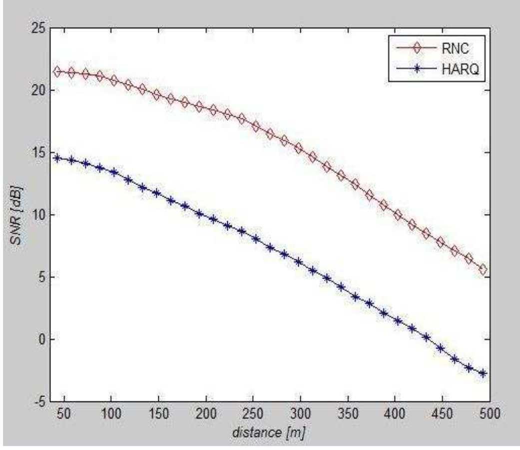

Fig. 6: SNR vs. Distance of MAC-RNC and MAC-HARQ

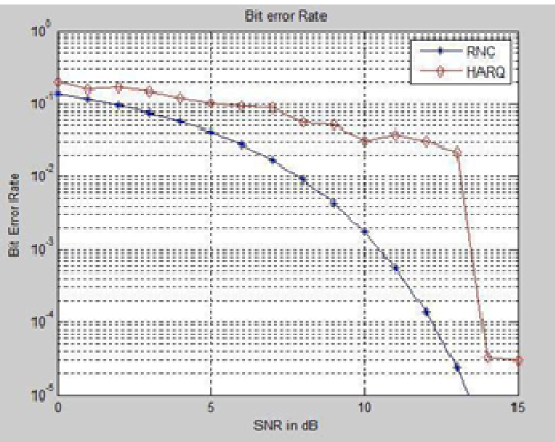

Fig. 7: BER vs. SNR of MAC-RNC and MAC-HARQ

$$\mathrm{BER}\ (i) = \sum_{j=1}^{N_s} P(j).BER^{(sim)}(j) \qquad (4.2)$$

where P(j),$1 \le j \le N_S$, is the substate probability distribution obtained as a discretized version of the exponential instantaneous SNR probability distribution law (normalized to the SNR interval of the *i*-th CQI state), and $\mathrm{BER}^{(sim)}(j)$ is the *j*-thsubstate BER obtained by PHY simulations. Finally, the average UE throughput R_{avg} is obtained as:

$$R_{avg}(d)=\pi\cdot R^T$$

where, $\boldsymbol{R}=\{R_1, R_2, \ldots.., R_{NCQI}\}$

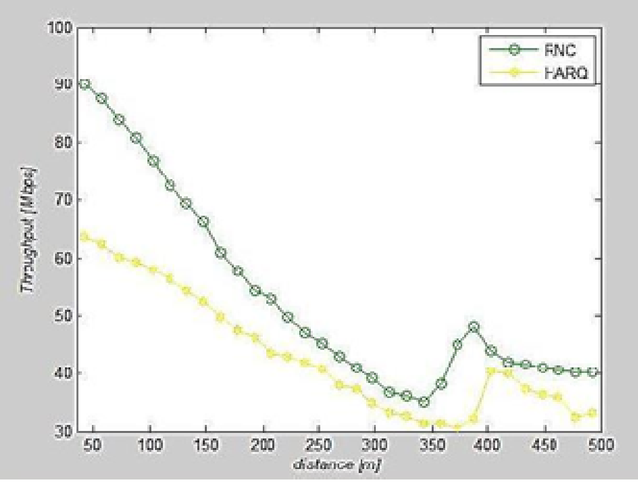

Fig. 8: Throughput vs. Distance of MAC-RNC and

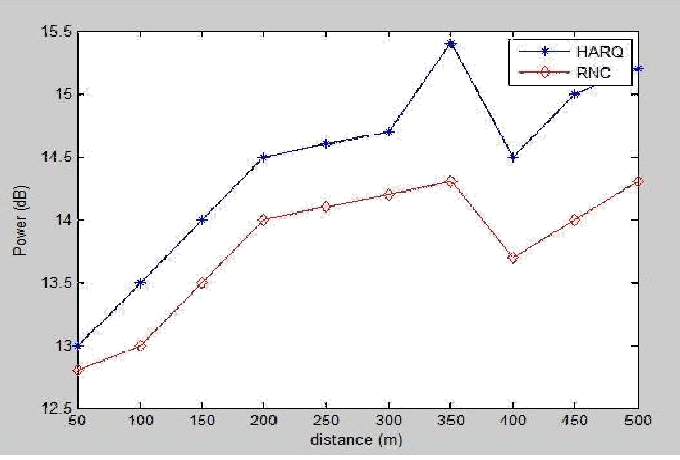

Fig. 9: Power vs. Distance of MAC-RNC and MAC-HARQ

with a relay node at 400m.MAC-HARQ with a Relay Node at 400m

This throughput benefit is achieved by using packet transmissions more efficiently, i.e., by communicating more information with fewer packet transmissions. The Maximum throughput is achieved when compared to HARQ because the RNC conserves the frequent Signaling messages which are later used for the data transmission. This increases the overall system throughput. RNC improves the throughput, but to maintain the throughput at the cell edges, a relay node is placed at the 400th m from the base station. This placement of HetNets give raise to the curve from 350m and reaches its peak value at 400m and drops along the further distance of the cell.

Power Consumption is the major disadvantage of the LTE systems, this was due to the frequent transmission of the HARQ signalling messages in MAC Layer. Power is also consumed in a large scale in the Base Stations. Whereas just for signalling, the Indian Telecom consumes approximately 26 TWh of power each year, which is equal to 3 billion litres of Diesel. Regarding Base Station, every single Base Stations consumes almost 60% to 80% of the total power just for signalling and overhead messages.

Another important issue is due to this power consumption about 290 Mega Tons of CO_2 is released just in India alone each year which is 1% of the total Atmosphere. If this continues, the future may have a devastating effect around the world with Global Warming.

Fig. 9 shows that the power consumed by the UE at the various distance is very less compared to the power consumption of HARQ. It also shows the power consumption at the relay node is very less. Hence, throughout the cell the system provided reduced power consumption. This may attract much applications further more to use the technique for conserving power.

Future Scope:

The Performance of the LTE-A communication system is further can be increased by combining the Performance of the RNC being implemented in Network Layer with the Performance of RNC being implemented at the MAC Layer. By this combination it will provide rapid improvement in Overall LTE-A Performance which will be more reliable and robust.

Conclusion:

Comparing the performance of RNC and HARQ in Rayleigh channel, it can be inferred that RNC is capable of conserving the resource by reduced signaling and overhead messages, among other techniques used previously in MAC layer. The power consumption caused by the HARQ is considered to be the major disadvantage for a LTE-A system; it also reduced the overall throughput and causes high BER. Whereas in RNC, due to its ability to reduce the overhead message, it provides high throughput and reduced power consumption. It also infers that rather than the traditional macrocell of an LTE system, the HetNets provides increased performance even in the cell edge by using an Relay Node. Moreover, RNC can offer less complexity and high resource allocation for the data’s and achieve high throughput almost 20% of the HARQ and reduced power of about 60% when compared to HARQ all over the cell of an LTE-A Network.

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