Improving Fairness Using ARQ messages in LTE Mobile Multi-hop Relay (MMR) Networks.

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Abstract— ***We consider extension of the FRTS (Frame Registry Tree Scheduler) to LTE multi-hop relay networks. In this paper we consider extension of the scheme to LTE multi-hop relay networks. One major contribution of our work lies in developing a scheduler which improves fairness using ARQs. ARQ messages originate from UEs or RNs on missed frames. The node with poor link quality tends to generate more ARQ messages. Based on this observation we elevate the priority of the packet when its transmission returns an ARQ message. This enables the UE/RN with poor link quality to have better chance to improve their throughput, leading to improved fairness for the network. Simulation with a 2-hop relay network with 1 eNodeB and 3 Relay nodes for regular traffic shows improvement of 12.6% and 15.5% respectively in terms of scheduling efficiency and fairness.***

Keywords-component; LTE; Multi-Hop; ARQ

I. INTRODUCTION

3GPP LTE(Long Term Evolution) system will provide data transmission rate up to 100Mbps and its standardization work is almost finished[1-2]. Introduction of relay network to LTE system seems to be inevitable to meet the relatively huge coverage request. FRTS [4] schedules frame preparation and creation efficiently with frame registry tree. Since FRTS is based on one-hop network, it considers only eNB as transmitter in downlink. In multi-hop relay networks, RNs also serve as transmitters and the frame structure should be modified to be used along with RNs.

Each DL subframe and UL subframe is divided into two portions, which are an access zone and a relay zone. The packets transmitted to the RNs in relay zone are transmitted to UEs in the access zone of the next frame.

In this paper, a traffic scheduling algorithm for LTE Mobile Multi-Hop Relay networks, referred to as the "ARQ aware Frame Registry Tree Scheduler"(A-FRTS) is proposed and evaluated. The main features of this scheduler are i) its ability to prepare in advance the structure of each time frame, and avoid complex processing before the frame header transmission, and ii) the ARQ aware scheduling that allows reasonable choice of retransmission traffic during congestion, and iii) the scheduling for Mobile Multi-Hop Relay networks.

TABLE I. COMPARISON OF PREVIOUS SCHEMES

Schemes	Multi-hop scheduling	ARQ processing
Simple	Common scheduling	Priority based standard [3]
FRTS[4]	No	No
A-FRTS (proposed)	Yes	Exploited for fairness improvement

The original FRTS[4] does not consider the ARQ and Multi-Hop Relay. In Table I, we compare with our proposed A-FRTS against FRTS and Simple scheduler. In LTE draft documents[1-2], there are almost no words about scheduling operations.

A-FRTS implements a multi-hop scheduling algorithm for resource efficiency and improved fairness. The bandwidth assigned to an RN in t frame's *relay zone* is determined from the estimation of the bandwidth to be used by the RN in (t+1) frame's *access zone*.

The FRTS and Simple scheme don't exploit ARQ. The ARQ message is defined in LTE draft documents, but the ARQ messages are generated mostly by stations with poor wireless links. Our A-FRTS scheduler exploits this ARQ messages for fairness improvement. Based on our observation that nodes with poor link quality tend to generate more ARQ messages, we develop a scheduling algorithm which raises priority level of a retransmission packet if the transmission of the packet generates an ARQ message. The packet which was unsuccessful in transmission will move to a queue with higher priority, obtaining better chance in scheduling transmission. This improves the throughput for RNs/UEs with poor link quality, leading to improved fairness to the network.

The rest of paper is organized as follows. Section II reviews the main characteristics of LTE. Section III introduces the proposed scheduler with focus on the actions required of frame preparation and creation. Section IV describes the simulation model used to evaluate A-FRTS against Simple scheduler and the obtained results. Section V concludes the paper and discusses future work.

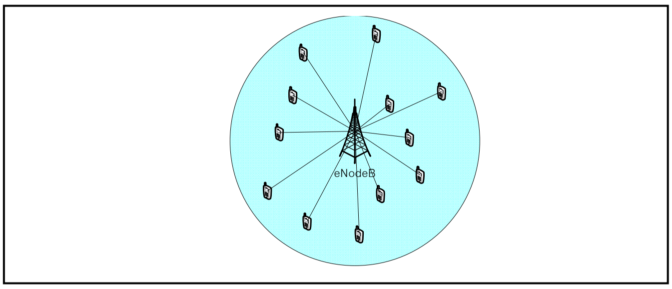


Figure 1. LTE network.

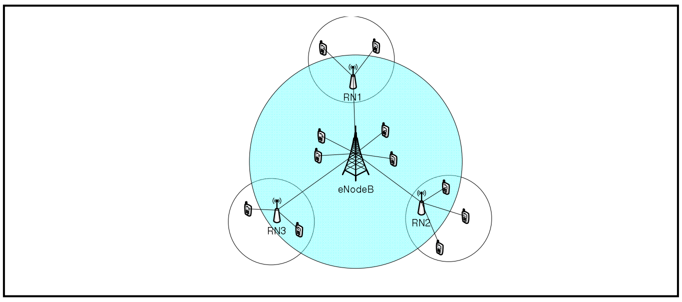


Figure 2. LTE multi-hop network(1-hop relay nodes are represented)

II. CURRENT SCHEDULING SCHEME IN LTE

A. *Scheduling algorithm for LTE*

We focus on PMP mode where the system architecture consists of: *i*) eNodeB (MMR-eNB), that have direct connections to backhaul services and are responsible for a specific area cell, *ii*) relay nodes (MMR-RN), that enhance coverage and throughput a eNB, and enable low power devices to participate in the network, *iii*) user equipment (MMR-UE).

The MMR-RN can be a fixed RN or a RN capable of mobility. It is assumed the MMR-RN will not generate user traffic of its own, but it is expected that the RN provide user access and support the generation of control and management messages that are necessary for proper relay operation.

Compared with the one in the LTE network [2], resource allocation in a LTE MMR network is more complicated as both the MMR-eNB and the MMR-RNs are involved in the resource allocation process. Additionally relay zone of *t frame* in MMR-eNB is based on access zone of *(t+1) frame* in MMR-RN (Fig.4).

We hypothetically imagine a simple scheduler (Simple) for the purpose of comparison.

The operations of Simple scheduler are as follows:

- In access zone scheduling, eNB and each RNs allocate resources to UEs with priority. In case of the frame with excess packets for transmission, the one of lowest priority packets can be moved to the next frame.
- In relay zone scheduling, eNB allocates fixed portion of resources to each RNs.
- Under distinction of RNs, eNB allocates resources to each UEs for next frame's access zone of each RNs.

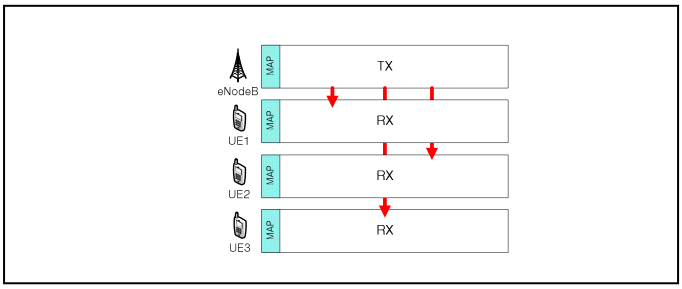


Figure 3. LTE frame structure in downlink Transmission takes only 1 frame.

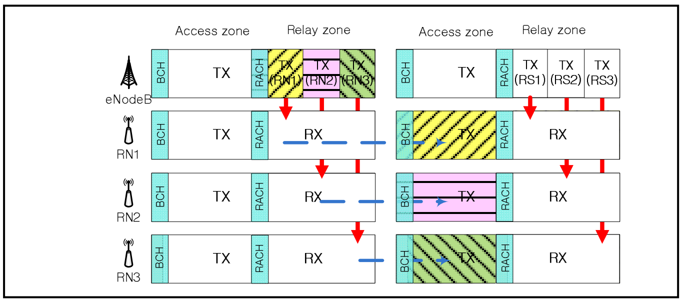


Figure 4. LTE multi-hop frame structure in downlink

In Simple scheduling algorithm, a packet of high priority can't be scheduled and a packet of low priority can be scheduled following super-RN since fixed portion is allocated for RNs in relay zone.

B. *Scheduling Service*

LTE can support multiple communication services (data, voice, video, etc.) with different QoS requirements. Each connection is associated with a single service flow and specifies a set of traffic and QoS parameters that quantify its traffic behavior and QoS expectations. This set includes the minimum reserved traffic rate, the maximum sustained traffic rate, latency and the traffic priority, etc. Every connection should belong to one of the different QoS classes.

The traffic scheduler located at the eNB decides on the allocation of the PSs in each time frame. Uplink scheduling is performed by the eNB with the aim of providing each node with enough bandwidth for uplink transmissions or opportunities for extra transmission requests. When a node needs additional bandwidth, it utilizes its transmission opportunities during contention periods or when it is polled by the eNB, depending on its agreed QoS characteristics, to pass its transmission requests. Downlink scheduling on the other hand, considers packets waiting for transmission at the eNB as implicit requests for bandwidth allocation.

C. *ARQ scheme*

In LTE, ARQ scheme is defined as an option. As the response of receiving a data packet, the receiver sends acknowledgement (ACK) message to the transmitter. If once a data packet isn't received or is received in errors, the receiver will use an ARQ feedback bitmap to provide the receipt status (i.e., ACK or NACK) of each ARQ block in it and only the negative acknowledged ARQ blocks will be retransmitted. The receiver with poor link generate ARQ message frequently. For system fairness, data packets requested ARQ should have more chance of retransmission.

We focus our discussion on the scheduler. Specially, we consider downlink scheduling with ARQ.

III. PROPOSED TRAFFIC SCHEDULER

A. Scheduling for multi-hop relay

LTE defines different QoS classes suitable for the channel Quality Indicator (CQI) which is returned by the User Equipment (UE). We assume 10 classes(QoS_Classes∋{C1, C2, …, C10}). Considering the complexity of the QoS provision mechanism in LTE, efficient traffic scheduling implies complex procedures and calculations. This means significant computational requirements, leading to expensive hardware. The proposed scheduler described here, referred to as the *"ARQ aware Frame Registry Tree Scheduler" (A-FRTS)*, is an extension to multi-hop relay of the *"Frame Registry Tree Scheduler" (FRTS)* [4]. It aims to efficiently guarantee LTE QoS parameters and distribute over time the computational complexity required for the time frame preparation. And the scheduler can easily deal with possible modifications of one or more transmission characteristics of a connection, such as the modulation..

The main objectives of A-FRTS are as follows:

- A per QoS service treatment of the transmissions should be possible, based on a specific priority strategy.
- Data packet transmissions should be organized in MMR networks
- Relay zone scheduling should be based on each RN's access zone of next frame.
- If ARQ is enabled for a connection, the data packet is taken advantage of contention by scheduler.
- The required processing complexity, before the beginning of a time frame transmission, should be minimum.

To accomplish the above objectives, A-FRTS uses the tree structure of Figure 1, referred to as the *Modified-Frame Registry Tree.* The tree consists of seven levels.

1st Level: Represents the time frames immediately following the present one, in a sequential order (i.e., TF_1 is immediately after the present frame, TF_2 the next one, etc.).

2nd Level: Represents the direction (uplink or down link).

3rd Level: Corresponds to the available modulation types.

4th Level: Represents direct access by eNB or relay access by RN.

5th Level: In this level, connections are organized per UE.

5.5th Level: Represents tag of ARQ or RE (RE means traffic that is excess traffic of previous frame).

6th Level: Represents the different kinds of QoS services.

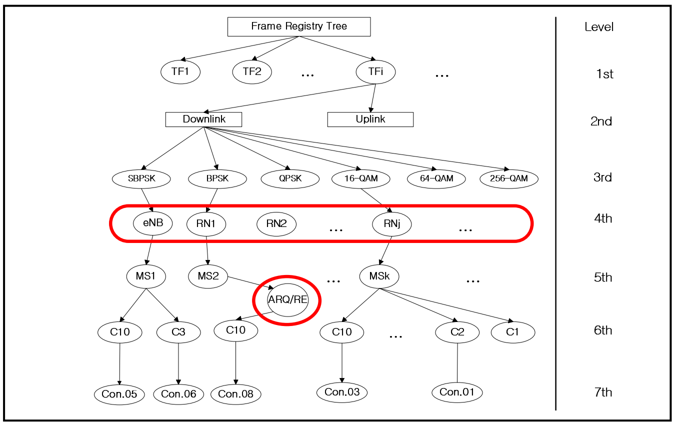


Figure 5. Modified-Frame Registry Tree.

7th Level: Consists of one leaf for every active connection in every time subtree, holding the number of data packets scheduled for transmission in that time frame.

1) Access/Relay Decision: Since the scheduler treats both new packets arriving for the downlink and new requests for packet transmissions from the uplink in the same way, only the downlink case is described here. While the FRTS is based on one-hop scheduling, A-FRTS considers multi-hop networks, so that the Frame Registry Tree of FRTS is modified as follows. In modified Frame registry tree (fig.5), 4th Level represents direct access by BS or relay access by RS and 5.5th Level represents tag of ARQ or RE(RE denotes packets that is delayed from previous frame)

User Equipment (UE) communicate with Relay Nodes (RN) as well as eNodeB (BS) in multi-hop networks (figure 2). UEs under eNodeB can get packets in TF_1, others can get packets in next frames (TF_2, TF_3, …) by number of hops. As the packets are arrived at the queue of eNodeB, the scheduler decides whether the packets to be transmitted in the next frame to choose access zone or relay zone.

2) Frame Creation ; Before the beginning of each time frame, the frame creation procedure decides on the frame contents and structure based on the information stored in the modified-Frame Registry Tree. Let us assume that at the beginning of a time frame there are m time frame subtrees (TF_1, …, TF_m). The next frame will be generated mainly from the first subtree (TF_1). The basic idea is that in case of empty slots these can be filled with one of the highest priority packets from the next subtrees (TF_2, TF_3, …TF_m), and for frame with excess packets for transmission, the one of lowest priority packets can be moved to the next frame subtree.

In LTE system, scheduler admits flows as long as there is enough bandwidth to satisfy the incoming request. So the available bandwidth (BW) satisfies as below.

$$BW \geq \sum_{C \in QoS\_classes} \sum_{i}^{N^C} Q_i^C[maxrate] \qquad (1)$$

where i is UE index, $Q_i^C[maxrate]$ is maximum_rate of QoS_class C and N^C is number of UEs that request QoS_class C. According to (1), scheduler creates access zone and relay zone in each frame. The main characteristics of MMR networks is that access packets are transmitted in access zone of the *t frame* ,and relay packets in the *t frame* are transmitted in access zone of the *(t+1) frame* by RN.

More specifically, the scheduler creates next frame as below.

Step 1: Access zone packets are chosen according to the basic idea.

Step 2: The bandwidth of RN in *t frame*'s relay zone is controlled by the bandwidth of RN in *(t+1) frame*'s access zone.

$$BW_{RS_j\_access_{t+1}} \geq \sum_{C \in QoS\_classes} \sum_{i}^{N_j^C} Q_{ij}^C[maxrate] \quad (2)$$

Step 3: whole relay zone follows the basic concepts without distinction of RNs. In case of empty slots these can be filled with one of the highest priority packets considering step 2.

$$BW_{relay} \geq \sum_{C \in QoS\_classes} \sum_{i}^{N_R^C} Q_i^C[maxrate] \quad (3)$$

where R is relay zone index.

B. *ARQ message*

If a node doesn't receive an intended packet or receive it with error, it sends ARQ message to upper layer. ARQ message can be generated by UEs or RNs. Generally, the node with poor link quality tends to request retransmission, which lowers the goodput, resulting in unfairness for the network. Figure. 6 shows queue structure to adjust priorities of the packets using the ARQ messages. If a C1(lowest priority QoS class) packet is requested for retransmission by an ARQ, its priority increases by 1. So the priority of the packet becomes equal to that of C2 queue. Consequently the retransmitted C1 packet now has better chance of transmission opportunity compared with other C1 packets to be transmitted.

As UE requests retransmission to RN (see Fig.7(b)), RN needs scheduler operation to transmit requested packet. RN with scheduling function can respond for ARQ message directly in next frame.

IV. SIMULATION

In order to measure the performance of the proposed scheduler, a simulation program that compares it against a simpler scheduler is constructed in C++. Now let us assume that whole network is a full-buffer model.

We use a scheduling efficiency (S_{eff}) metric as in Equation(4) which is similar to the SE metric [5].

$$S_{eff} = \sum_{C \in QoS\_classes} (Q^C[priority] * \sum_{i}^{N^C} Q_i^C[maxrate]) \quad (4)$$

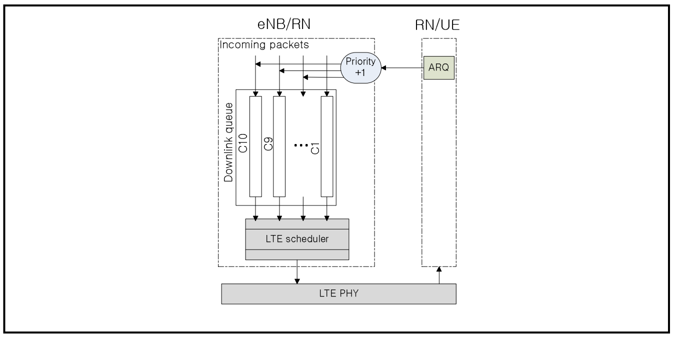
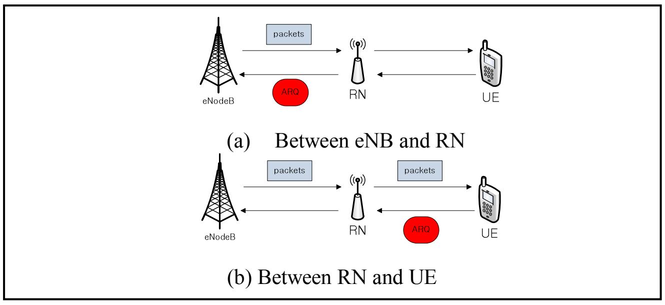


Figure 6. Queue structure to prioritize for ARQ.



(a) Between eNB and RN

(b) Between RN and UE

Figure 7. Packets transmission failure.

The S_{eff} metric measures how efficiently resources are used. When the amount of traffic is same, BS schedules high priority first, then, lower priority for system fairness. The simple scheduler allocates same amount of resource to all RNs in relay zone scheduling. In case one RN has higher priority packets and another RN has lower priority packets, the relay zone scheduling is out of balance. However, the proposed scheduler considers *t frame*'s relay zone and *(t+1) frame*'s RN access zone. Traffic in each RN is determined below the capacity of access in next frame. Then, scheduler considers excess or empty slots without distinction of RNs.

Figure. 8 shows the decrement of S_{eff} by the average standard deviation of QoS_classes. As the distribution of QoS_classes that each RN request has difference largely, the result is showed clearly. If RN_1 doesn't contain C1 packets and has excess traffic, RN_1 must carry high priority traffics over to next frame. In this case, the efficiency of system drops. Since the proposed scheduler considers relay zone without distinction of RN, the S_{eff} of system decreases slightly.

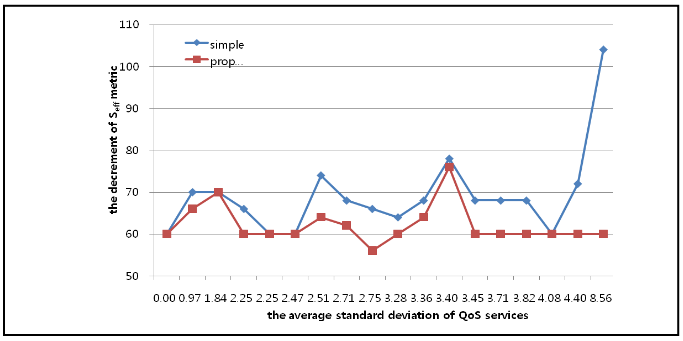


Figure 8. Comparison of S_{eff} decrement.

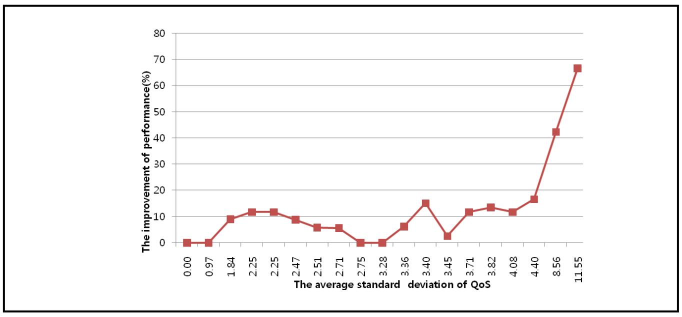


Figure 9. The improvement of performance.

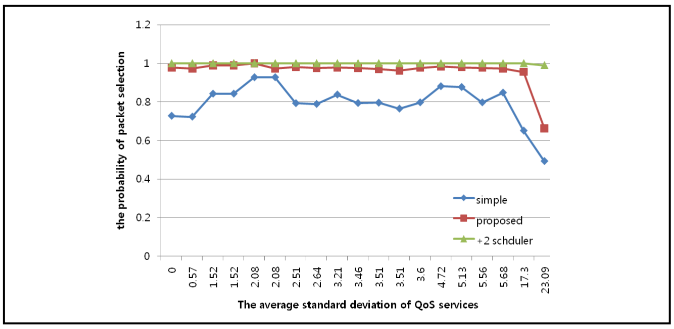


Figure 10. Comparison fairness by the probability of packet selection.

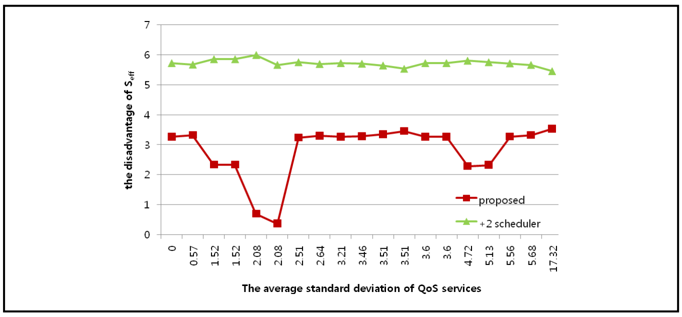


Figure 11. The disadvantage of S_{eff}.

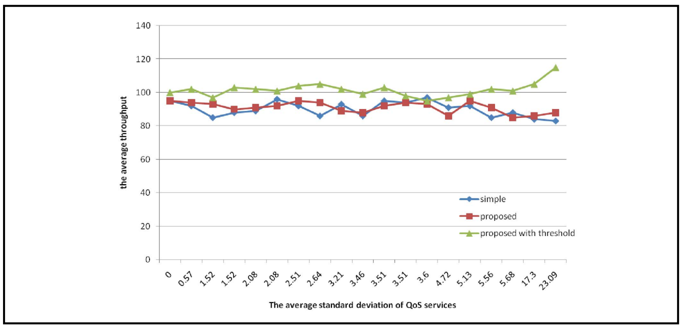


Figure 12. The effect of threshold.

Figure. 9 shows the improvement of performance by S_{eff}. According to increasing average standard deviation of QoS_classes, the performance is not always evaluated. For example, if each RN has too many C1 packets or a few packets, the performance improvement can't be expected in spite of high average of standard deviation of QoS_classes, which is non-realistic. In Figure.9, the mean of performance improvement is 12.61%.

The packets requested ARQ sustains previous QoS priority for contention in simple scheduler. However, proposed scheduler increase priority by 1 level, So that ARQ packets are chosen better in contention. The node with poor link requests more often retransmission and the packet selection with high probability means good fairness (Figure.10).

In case of increasing priority by 2 level, the packet selection is guaranteed more obviously while the system undergoes damage of S_{eff}. (figure.11)

For user fairness, we proposed ARQ mechanism using priority deformation. However, we set up throughput threshold for system total throughput. (figure.12)

In simulation, users under 70% of the average throughput can't transmit the packet. So system throughputs are improved by 10.6% and 11.5% against simple and proposed algorithm respectively.

V. CONCLUSION

The scheduler proposed in this paper, referred as A-FRTS (ARQ aware Frame Registry Tree Scheduler), aims at scheduling for LTE multi-hop network. A-FRTS apply FRTS's scheduling advantages to multi-hop. In particular, proposed scheduler focus on *(t+1) frame* as well as *t frame* for relay zone scheduling and maximize resources efficiency in relay zone. As the ARQ message is generated, the node with requesting ARQ takes advantage of contention through increasing priority for system fairness. A notable advantage of the scheduler is its scalability that support almost networks using relay station.

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