LTE_FICC: A New Mechanism for Provision of QoS and Congestion Control in LTE/LTE-Advanced Networks

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Abstract. In Long Term Evolution (LTE)/LTE-Advanced architecture, the basic schedulers allocate resources without taking congestion at the Evolved NodeB (eNodeB's) output buffer into account. This leads to buffer overflows and deterioration in overall Quality of Service (QoS). Congestion avoidance and fair bandwidth allocation is hardly considered in existing research for the LTE/LTE-Advanced uplink connections. This paper introduces a mechanism for LTE and LTE-Advanced, *LTE Fair Intelligent Congestion Control (LTE_FICC*), to control congestion at an eNodeB. LTE_FICC jointly exists with the scheduler at the eNodeB to guarantee efficient traffic scheduling, in order to make the output buffer operate around a target operating point. LTE_FICC also overcomes the problem of unfair bandwidth allocation among the flows that share the same eNodeB interface. LTE_FICC is simple, robust and scalable, as it uses per queue rather than per flow accounting. To evaluate the effectiveness of the proposed algorithm, simulations were performed in Opnet using LTE module. The results demonstrated that LTE_FICC controls the eNodeB buffer effectively; prevents overflows; and ensures the QoS of flows in terms of fair bandwidth allocation, improved throughput and reduced queuing delay.

Keywords: Congestion control · QoS · Fairness · Throughput · Queuing delay · LTE · Opnet

1 Introduction

The 3rd Generation Partnership Project (3GPP) introduces the new architecture recognized as Evolved Packet System (EPS) in Rel. 8, as part of two parallel projects, System Architecture Evolution (SAE) and Long Term Evolution (LTE). SAE specifies the IP-based network core of the system called Evolved Packet Core (EPC). LTE defines the Radio Access Network (RAN) [1]. Motivated by the rising demands of advanced mobile services with higher data rates and stringent Quality of Service (QoS) requirements, 3GPP introduces LTE-Advanced in Rel.10. It supports data rate of 1 Gbps in downlink (DL) and 500 Mbps in uplink (UL) in scenarios of low mobility.

The 3GPP introduces LTE/LTE-Advanced with Orthogonal Frequency Division Multiplex (OFDM) based air interface. LTE supports scalable bandwidth up to

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20 MHz. LTE-Advanced supports bandwidth extension up to 100 MHz via Carrier Aggregation (CA). CA allows a mobile to transmit or receive on up to five Components Carriers (CCs), each of which can have maximum bandwidth of 20 MHz.

LTE/LTE-Advanced supports transmission in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes. In FDD mode, Frame structure type 1 is used. In frame structure type 1, each radio frame is 10 ms long and consists of 10 subframes of length 1 ms each. Each subframe consists of 2 slots of length 0.5 ms each. In time domain, each slot consists of either 6 or 7 OFDM symbols for long or short cyclic prefix (CP) respectively [2]. In frequency domain, each slot is described by a Resource Block (RB) and consists of 12 subcarriers each over 6 or 7 OFDM symbols.

To guarantee the service differentiation and provision of Quality of Service (QoS), LTE/LTE-Advanced employ the concept of bearer. A bearer identifies packet flows from one network element to another. Each bearer is associated with *QoS Class Identifier* (QCI) and *Allocation and Retention Priority* (ARP). QCI classifies the QoS class to which the bearer belongs and describes QoS parameters such as resource type, data rate, error rate and delay. ARP is an attribute of the bearer that indicates which bearer can be preempted by high priority bearers.

With respect to resource type, LTE/LTE-Advanced support *Guaranteed Bit Rate* (GBR) bearers and *Non Guaranteed Bit Rate* (non_GBR) bearers. In this paper, they are referred to as Classes of Bearers (CoBs). A GBR bearer is established or modified only on demand and reserves network resources corresponding the GBR value associated with it. A non_GBR bearer does not reserve network resources and may experiences congestion related packet losses [3]. Every QCI (GBR and Non-GBR) is associated with a priority level.

Scheduler plays a crucial role to ensure the provision of QoS requirements of the applications, which are defined in terms of bandwidth, delay and loss. LTE/LTE-Advanced eNodeB MAC sublayer schedules UL and DL transmissions and allocates RBs to the competing users. Scheduling is performed in every subframe. The basic schedulers like Round Robin (RR) and equal capacity sharing algorithm do not consider the QoS characteristics of the radio bearers. Additionally, none of these scheduling algorithms considers the queue length at an eNodeB. As a result, during congestion period when the core network is loaded, the queue at an eNodeB output buffer reaches its maximum and packets' loss starts. This leads to deterioration in the QoS experienced by existing connections.

The authors in [4] present CC scheme to provide fairness in heterogeneous radio access networks based on Radio Link control (RLC) packet discard. A congestion control (CC) mechanism is proposed in [5] that mitigates load in the network by removing the low priority bearers until the system load reaches to a predefined target value. The paper does not clearly discuss how the target load can be defined for a network. The authors in [6] propose a congestion control mechanism that protects an eNodeB output buffer from overflow by controlling the TCP advertisement window. RLC layer in an eNodeB monitors the buffer utilization and sets the congestion flag once it reaches to the threshold. So the proposed scheme violates the protocol layer design principles. The authors in [7] propose queue aware scheduling technique. The paper studies the performance of various queue aware scheduling schemes with an end-to-end congestion control scheme that controls the rate of elastic traffic and consequently affects the buffer status. The scheme is proposed for DL only. The end-to-end congestion scheme used in the paper involves the overhead of congestion field that is added in every packet.

The above mentioned schemes to perform load balancing are either based on thresholds or are applicable to a specific protocol, such as TCP only. They merely discuss the fair bandwidth allocation among flows of same CoB.

In this paper, we introduce an effective congestion control mechanism, namely LTE-Fair Intelligent Congestion Control (LTE_FICC). As discussed, the QoS framework of LTE-Advanced and LTE is the same. Therefore, the scheme is proposed for the uplink of both LTE and LTE-Advanced but is named as LTE_FICC for the sake of conciseness. LTE_FICC deals with both unfair bandwidth allocation and the congestion issues encountered in LTE/LTE-Advanced networks. It maintains the network traffic around a target operating point, hence avoids congestion and loss at the eNodeB output buffer. LTE_FICC uses a rate allocation scheme that takes degree of congestion at the eNodeB's output buffer into account. It estimates per queue fair share for all classes of bearers and sends the estimated rates as a feedback to the underlying scheduler at the eNodeB. LTE_FICC is simple because it employs a small number of parameters. It is effective in terms of operating with any basic underlying scheduling algorithm to minimize delay and to maintain high throughput.

The paper is organized as follows. Proposed scheme is presented in Sect. 2. Section 3 discusses the simulation setup and results. Finally, conclusion is given in Sect. 4.

2 Proposed Scheme

In this paper we introduce a new congestion control scheme namely LTE_Fair Intelligent Congestion Control (LTE_FICC) based on the basic principles of explicit feedback congestion control scheme namely Fair Intelligent Congestion Control (FICC) introduced in [8] for wired networks. FICC main idea is as follows.

1. FICC tries to maintain the queue length (Qlen) close to a target operating point (Q_0), so that the queue neither reaches to its capacity nor becomes empty and hence guarantees that the link is never idle unnecessarily.
2. In FICC, egress router uses Resource Discovery (RD) packets to probe available resources from routers inside the Diff-serve domain.
3. FICC adjusts the allowed class rate to minimize the variations in the buffer queue length.
4. FICC shares bandwidth equally among the connections of the same class. The left over bandwidth is shared fairly among connections that can take the additional share. To achieve this objective, when the network operates below a target point, FICC oversells the bandwidth to the connections in need.
5. FICC maintains information only per output queue, to make it more scalable.

```
FICC : At each router interface

If (receive RD (CCR,ER,DIR) = forward)
    If (Qlen > Q0)
        If (ACR < MACR)
                MACR=MACR + β * (ACR-MACR)
    Else
                MACR=MACR + β * (ACR-MACR)
If (receive RD (CCR,ER,DIR) = backward)
    If (Qlen > Q0)
        f(Q) = (Buffer_Size-Qlen) / (Buffer_Size-Q0)
    Else                                              (1)
        f(Q) = (α-1)*(Q0-Qlen) / Q0
  ER = Max (MinER, min(ER ,f(Q) * MACR)
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$$f(Q) = \frac{(Buffer\_Size - Qlen)}{(Buffer\_Size - Q_0)} \quad \text{if } Qlen > Q_0; \qquad f(Q) = \frac{(\alpha-1)*(Q_0 - Q_{len})}{Q_0} \quad \text{else} \tag{1}$$

The main aim of FICC is to calculate the explicit rate which reflects how much traffic could be handled by a transit router within the network. The calculated explicit rate is sent as a feed back to the source nodes. Mean explicit rate is defined as follows.

$$ER = MACR * f(Q) \tag{2}$$

Instead of fixed congestion thresholds which lead to unfairness in the network, FICC defines a target operating point (Q_0). To detect congestion, FICC employs an efficient function of queue size called "queue control function". The queue control function expresses the degree of network congestion that a router can tolerate.

f(Q) is a linear function as shown in Eq. (1). It is specified by three parameters namely α, Q_0 and Buffer_Size as shown in Eq. (1). Buffer_Size is the total size of the output buffer at the router. α can be considered as an oversell factor when the network is underutilized. The value of oversell factor determines how much traffic is encouraged to put inside the network and is higher than 1. f(Q) returns value between 0 to 1 for the queue length in the range of [Q_0, Buffer Size] and between 1 to α for the queue lengths in the range of [0, Q_0].

In FICC, router estimates the current traffic rate of all aggregates passing through it and allocates a fair share of the available bandwidth among its aggregates. For this purpose, FICC uses MACR (Mean Allowed Class Rate) and ACR (Allowed Class Rate). The MACR is an average of the current allowed rates of all aggregates [8]. The ACR is the rate at which the edge router admits a flow in the network.

As mentioned before, the QoS framework of LTE-Advanced and LTE is the same and LTE_FICC is the rate allocation scheme only, so LTE_FICC is proposed for both the networks. LTE_FICC is based on the basic idea of FICC in terms of buffer control. To make it effective for LTE/LTE-Advanced networks, new aspects have to be considered and hence LTE_FICC is distinct from FICC in following ways.

- The output queue status of an eNodeB depends on the output link capacity as well as on the capacity of the EPC. So a large queue length at an eNodeB buffer serves as an indication that the EPC is congested.

- FICC sends the explicit rate as a feedback to the source nodes of the end-to-end connection whereas LTE_FICC is employed as a separate module in an eNodeB. It estimates the expected rate for each CoB and passes it to the scheduler.
- LTE_FICC is flexible because it can operate with any underlying basic scheduler.
- LTE_FICC allocates resources fairly among flows of each CoB namely GBR and non_GBR.
- As the LTE/LTE-Advanced environment defines different types of bearers, so LTE_FICC takes different QoS requirements of each type of bearer into account.

2.1 Queue Control Function

LTE_FICC uses the same queue function as in FICC given in Eq. (1).

2.2 Expected Rate of Each Class of Bearer (ER_{CoB})

In order to keep the queue length around the target operating point, LTE_FICC estimates the current bandwidth allocated to connections of each CoB (GBR and non_GBR) and then calculates the expected rate (ER) for each CoB using the queue control function. To estimate the current bandwidth allocated to flows of each CoB, LTE_FICC similar to FICC, uses a variable named MACR but one for each CoB ($MACR_{CoB}$). We suggest two MACRs corresponding to two classes of bearers, namely $MACR_{GBR\_Total}$ and $MACR_{NonGBR}$.

$MACR_{GBR\_Total}$ maintains the mean value of the bandwidth allocated to all active connections of GBR bearers. It is obtained as the sum of $MACR_{GBR}$ and $MACR_{GBR\_Ad}$ and is estimated as follow.

$$MACR_{GBR\_Total} = MACR_{GBR} + MACR_{GBR\_Ad} \tag{3}$$

In Eq. (3) $MACR_{GBR}$ is the estimate of the bandwidth allocated to all GBR bearers to meet their respective GBR. $MACR_{GBR\_Ad}$ refers to the estimate of the additional bandwidth allocated to all GBR bearers, above their individual GBR, to meet their respective MBR. GBR bearers always obtain GBR even when the network is congested. Therefore, LTE_FICC operates only on $MACR_{GBR\_Ad}$, as it is the only part of resource allocation to GBR bearers that can be controlled by LTE_FICC. The resources allocated above the GBR will be referred to as GBR_Ad hereafter. $MACR_{non\_GBR}$ maintains the mean value of bandwidth allocated to all active connections of non_GBR bearers. In every sub frame, the scheduler at the eNodeB after allocating resources to flows, updates the values of $MACR_{GBR}$, $MACR_{GBR\_Ad}$ and $MACR_{nonGBR}$ as in Eq. (4).

$$\begin{aligned}
&if\ Qlen > Q_0\\
&\quad if\ \frac{ACR_{CoB}(t)}{Weight[QCI]} < MACR_{CoB}(t-1)\\
&\qquad MACR_{CoB}(t) = MACR_{CoB}(t-1) + \beta * \left(\frac{ACR_{CoB}}{Weight[QCI]} - MACR_{CoB}(t-1)\right) \qquad (4)\\
&else\ if\ Qlen < Q_0\\
&\qquad MACR_{CoB}(t) = MACR_{CoB}(t-1) + \beta * \left(\frac{ACR_{CoB}}{Weight[QCI]} - MACR_{CoB}(t-1)\right)
\end{aligned}$$

In Eq. (4), β is an exponential average factor. $ACR_{CoB}(t)$ represents the actual bandwidth allocated to active connections in current subframe (t). $ACR_{CoB}(t)$ is estimated as follows.

$$ACR_{CoB}(t) = ER_{CoB}(t) * Weight[QCI] \tag{5}$$

Weight [QCI] is weight assigned by scheduler to each QCI based on its priority level in respective CoB and is further discussed in Sect. 3.4. For Example, in this paper QCI 1, 2, 3 and 4 from GBR CoB and QCI 6, 7, 8 and 9 from NonGBR CoB are assigned weights of 4, 3, 2 and 1 respectively. $ER_{CoB}(t)$ is the expected rate of each CoB and is estimated by LTE_FICC as in Eq. (6).

In Eq. (4), $MACR_{CoS}(t-1)$ and $MACR_{CoS}(t)$ reflects the mean of the allowed class rate of all active connections per class of service in previous and current frame respectively. When the network load exceeds the target operating point that is the Qlen is more than Q_0, LTE_FICC does not allow the $MACR_{CoB}(t)$ to increase further. Therefore, $MACR_{CoB}(t)$ does not track any value of current allocation ($ACR_{CoB}(t)$/ weight [QCI]) larger than current $MACR_{CoB}(t-1)$. The $MACR_{CoB}$ is regarded as an optimal mean allowed class rate if the network operates at the target operating point and the ER_{CoB} is set equal to it. While if the queue length is larger/smaller than the target operating point, the desired expected rate of each CoB is calculated as a function of f(Q) and corresponding $MACR_{CoB}$.

$$ER_{CoB}(t) = MACR_{CoB}(t-1) * f(Q) \tag{6}$$

2.3 Congestion Control Algorithm

LTE_FICC is executed only once in every subframe before the resources are allocated to connections by the scheduler.

The aim of LTE_FICC is to estimate the expected rate for each CoB that is non_GBR (ER_{non_GBR}) and GBR_Ad (ER_{GBR_Ad}) based on the current bandwidth allocated to the connections of each CoB that is $MACR_{CoB}$ and the queue control function f(Q).

2.3.1 Description of Algorithm

LTE_FICC sets the target operating point at a preset Buffer Utilization Ratio (BUR). It acquires the value of queue length from the router's output interface. It also obtains the estimates of $MACR_{CoB}(t-1)$ from the scheduler as shown in Fig. 1. LTE_FICC, estimates the degree of network congestion by calculating the f(Q).

When f(Q) is less than 1, indicating there is congestion in the network, LTE_FICC reduces the bandwidth allocated to all the non_GBR bearers. The step size of degradation is controlled by f(Q) as it provides an estimation of how much degradation is applied on this class of traffic. LTE_FICC then based on the degradation applied on

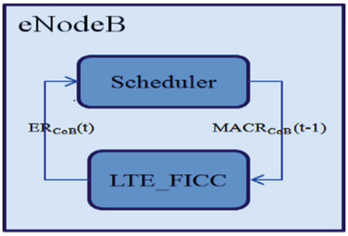

Fig. 1. LTE_FICC Module at eNodeB

non_GBR bearers, updates the estimates of Qlen, f(Q), $MACR_{non\_GBR}$ and the ER_{non_GBR}. LTE_FICC keeps on reducing the ER_{non_GBR} until either the f(Q) is equal to or greater than 1 or ER_{non_GBR} reaches to minimum number of bits that must be allocated to a connection in UL (MIN_UL).

After degrading the connections of non_GBR, LTE_FICC again estimates congestion using f(Q), if f(Q) is again less than 1 indicating network is still operating above the target operating point, LTE_FICC reduces the additional bandwidth allocated above the GBR (GBR_Ad) to all the connections of the GBR CoB. LTE_FICC then based on the degradation applied on GBR bearers, updates the estimates of Qlen, f(Q), $MACR_{GBR\_Ad}$ and the ER_{GBR_Ad}. LTE_FICC keeps on reducing the ER_{GBR_Ad} until either the f(Q) is equal to or greater than 1 or ER_{GBR_Ad} reaches to minimum number of bits that must be allocated to a bearer in UL (MIN_UL).

When f(Q) is greater than 1, indicating network is operating below its target level, LTE_FICC raises the additional bandwidth share above the GBR of all the GBR bearers. The step size for the share increase is still determined by f(Q) but at a different rate indicating how far the network is underutilized. LTE_FICC then based on the upgradation applied on GBR bearers, updates the estimates of Qlen, f(Q), $MACR_{GBR\_Ad}$ and the ER_{GBR_Ad}. LTE_FICC keeps on increasing the ER_{GBR_Ad} until either the f(Q) is equal to or less than 1 or ER_{GBR_Ad} reaches to maximum number of bits (MAX_UL) that can be allocated to a bearer using Max_MCS and the maximum number of RBs in UL subframe (RB_UL_Subframe). Max_MCS is the maximum Modulation and Coding scheme (MCS) that can be supported by the LTE/LTE-Advanced networks for the UL.

After upgrading bandwidth allocated to flows of GBR bearers, LTE_FICC recalculates the f(Q) and if again f(Q) is greater than 1, indicating network is still operating below its target level, LTE_FICC raises the bandwidth share of all non_GBR bearers. LTE_FICC then based on the upgradation applied on non_GBR bearers, updates the estimates of Qlen, f(Q), $MACR_{non\_GBR}$ and the ER_{non_GBR}. LTE_FICC keeps on increasing the ER_{non_GBR} until either the f(Q) is equal to or less than 1 or ER_{non_GBR} reaches to maximum number of bits (MAX_UL) that can be allocated to a bearer using Max_MCS and the RB_UL_Subframe.

```
Algorithm LTE-FICC:
  Initialization
                Q_0 = BufferSize * BUR
                MIN_UL   := 56
                MAX_UL   := Max_MCS * RB_UL_Subframe
1. Obtain Value of Current Qlen from BS output interface.
2. Obtain value of MACR_GBR_Ad and MACR_nonGBR from the scheduler.
3. Calculate f(Q) using Eq.(1).
4.
If f(Q) <1  /*Degradation Process*/
  For each CoB Non_GBR and GBR_Ad
     ER_CoB := MACR_COB *f(Q)
     Do While ER_CoB > MIN_UL AND f(Q) < 1
        Qlen   := Qlen - RB_UL_Subframe *(MACR_CoB - ER_CoB)
        ACR_CoB := ER_CoB
         Recalculate f(Q) using Eq.(1).
        Update MACR_CoB using Eq.(4).
        ER_CoB := MACR_COB *f(Q)
      End Do While
  End For
Else If f(Q > 1 /*Upgradation Process*/
  For each CoB GBR_Ad and Non_GBR
     ER_CoB := MACR_COB *f(Q)
     Do While ER_CoB < MAX_UL AND f(Q) > 1
         Qlen := Qlen - RB_UL_Subframe *(MACR_CoB - ER_CoB)
        ACR_CoB := ER_CoB
         Recalculate f(Q) using Eq.(1).
        Update MACR_CoB using Eq.(4).
        ER_CoB := MACR_COB *f(Q)
      End Do While
  End For
 End If
End If
Pass the estimated ER_GBR_Ad and ER_non_GBR to the Scheduler.
```

Once the expected rate of non_GBR and GBR_Ad is determined for the current subfarme, LTE_FICC passes the values of ER_{non_GBR} and ER_{GBR_Ad} to the scheduler as shown in Fig. 1.

2.4 Modified Round Robin (MRR)

The LTE module of opnet simulator [9] uses proportional fair scheduling to allocate resources to GBR connections to meet their respective GBR. It uses either equal capacity sharing algorithm or round robin algorithm to allocate resources to NonGBR, as well as to GBR connections above their respective GBR. In every subfarme, these basic scheduling algorithms always start scheduling from the highest priority QCI in a specific Class of bearer (CoB) (such as QCI 1 in GBR CoB and QCI 6 in NonGBR CoB) and keep on scheduling until all the queues at that priority level are empty. Consequently, these basic schedulers lead to unfair bandwidth allocation in the network. So we modified RR algorithm to ensure that connections at all priority levels are served.

The modified round robin algorithm always starts from the highest priority QCI in each CoB and in a RR manner scans to find a nonempty queue for scheduling. Once a queue is scheduled or there is no non empty queue at that level, the algorithm moves to next low priority QCI. The algorithm will continue to the next low priority levels and scan all queues from there too until a non empty queue is found. To maintain differentiation among different QCIs of a specific CoB, the modified round robin scheduling algorithm allocates resources to flows equals to ER_{CoB} X weight[QCI]. Once resources are determined then scheduler applies a binary search on the TB size table given in [10] for the value of ER_{CoB} X weight[QCI] and obtains the corresponding MCS and number of RBs to be allocated to the connection.

In this way, the modified round robin ensures that queues from all priority levels are scheduled. Also, it provides service differentiation according to the assigned weights.

3 Simulation Results

3.1 Simulation Setup

The overall goal of the simulation is to analyze the performance of the proposed algorithm to meet the QoS requirements of each class of bearer in terms of fairness, throughput and delay in a congested scenario. The simulations have been performed in system level simulator Optimized Network Engineering Tool (OPNET) release 17.1.A [9], using the LTE module. In the current simulation setup, User Equipments (UEs) are connected to an eNodeB that in turn is connected to the EPC. The EPC is connected to the server through the internet to reflect the actual deployment of the end-to-end network. The eNodeB operates in FDD mode and uses physical profile of 3 MHz bandwidth. The target point is set at 1/32 of the total buffer capacity of 3 Mbps. The link capacity between eNodeB and EPC is set at 1.3 Mbps to depict a high congestion scenario.

In the current simulation scenario, one cell is taken with a GBR UE and 7 nonGBR UEs. For the simulation the Max_MCS for all UEs is set at 15. The GBR_UE has two GBR bearers each with GBR of 64 kbps. The GBR UE transmits VOIP G.711 and 256 kbps H.263 video streams using GBR bearers with QCI-1 and QCI-4, respectively. Non_GBR UEs transmit VoIP G.711, 256 kbps H.263 video streams and 64 kbps web traffic using bearers with QCI-7, QCI-8 and QCI-9, respectively. The trace file for the 64 kbps and 256 kbps H.263 encoded Jurassic Park movie was obtained from the website in [11]. All connections start transmission at around 100 ms of the simulation and stop at end of simulation. The total simulation time is 500 s.

For the comparison a reference scenario is taken without the proposed LTE_FICC and without the modified round robin algorithm.

3.2 Queue Length (Qlen) and Traffic Dropped

Figure 2 shows Qlen at the eNodeB output buffer. Figure 2 confirms that if during the congestion periods, the scheduler allocates resources without taking the capacity of the output buffer at the eNodeB into account, a point will come when buffer overflows and the packets drop starts as shown in Fig. 3.

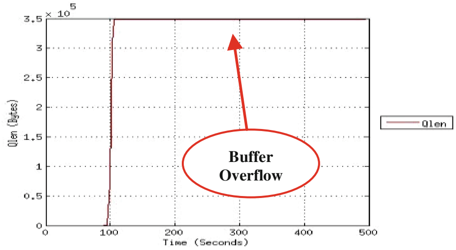

Fig. 2. Qlen (Bytes) at eNodeB without LTE_FICC

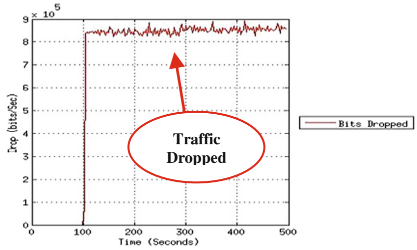

Fig. 3. Traffic dropped (bits/Sec) at eNodeB without LTE_FICC

Figure 4 shows the Qlen at the eNodeB output buffer with proposed LTE_FICC. With LTE_FICC, as soon as the Qlen reaches to Q_0, the LTE_FICC starts its operation and as designed maintains the Qlen close to the $Q_{0.}$ Consequently, there is no loss at the eNodeB output interface as indicated by Fig. 5.

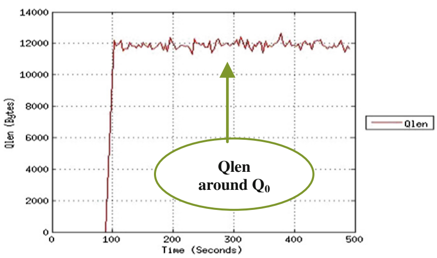

Fig. 4. Qlen (Bytes) at eNodeB with LTE_FICC

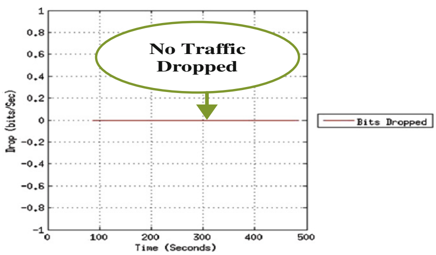

Fig. 5. Traffic dropped (bits/Sec) at eNodeB with LTE_FICC

3.3 Average Queuing Delay

Figures 6 and 7 show the queuing delay at the eNodeB output buffer. Initially, as there is less amount of data in the queue, so delay is less. As the transmission starts the amount of data in the queue increases and hence the delay increases. Figure 6 shows very high queuing delay which can be attributed to the fact that when LTE_FICC is not applied, the queue reaches to the maximum buffer capacity as shown in Fig. 2 and results in high delay. Figure 7 shows as LTE_FICC maintains queue length close the target point so the queuing delay is very low.

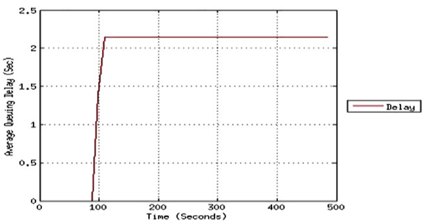

Fig. 6. Queuing Delay (Secs) without LTE_FICC

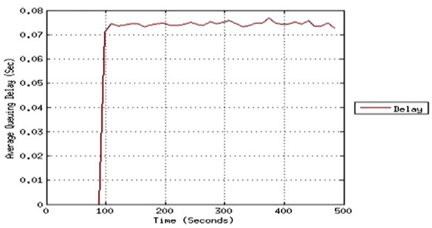

Fig. 7. Queuing Delay (Secs) with LTE_FICC

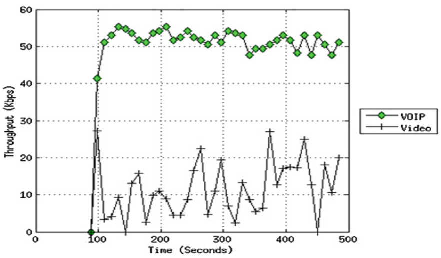

Fig. 8. Throughput (kbps) of GBR Bearers without LTE_FICC

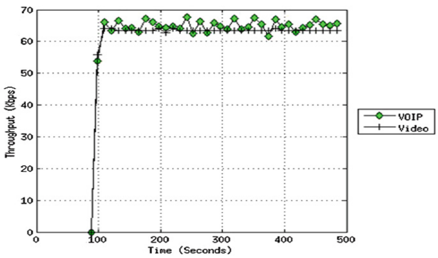

Fig. 9. Throughput (kbps) of GBR Bearers with LTE_FICC

3.4 Throughput of GBR Bearers

Figure 8 shows the throughput of GBR bearers without the application of LTE_FICC. It shows that the GBR bearers are getting less than the GBR value of 64 kbps. It is due to the fact that when the queue length of the buffer at an eNodeB reaches its maximum capacity, it starts dropping the packets in FIFO order as shown in Fig. 3.

LTE_FICC upgrades or degrades only the resources allocated above the GBR value of GBR bearers. Therefore, flows of GBR CoB get the requested GBR as shown in Fig. 9.

3.5 Fair Resource Allocation

3.5.1 Fair Resource Allocation Among QCIs of Non_GBR CoB

Figure 10 shows the cumulative throughput for different QCIs of non_GBR CoB when equal capacity sharing algorithm or RR allocates resources. Figure 10 shows the throughput of web application with lowest priority QCI is almost zero as the two algorithms always start scheduling with highest priority QCI and serve it until all queues at that priority level are empty and results in unfairness to connections of low priority QCI.

Figure 11 shows modified round robin with LTE_FICC ensures that queues at all priority levels within the non_GBR CoB are served. To provide differentiation as the modified RR allocates resources according to the assigned weights of QCIs, so the throughput of each QCI is in the order of corresponding priority and hence proved

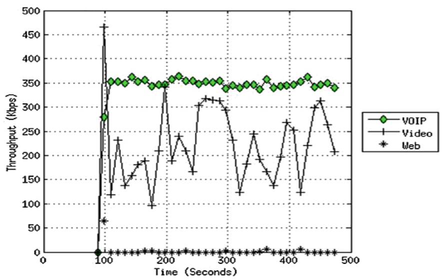

Fig. 10. Total Throughput (kbps) of Non-GBR bearers without LTE_FICC

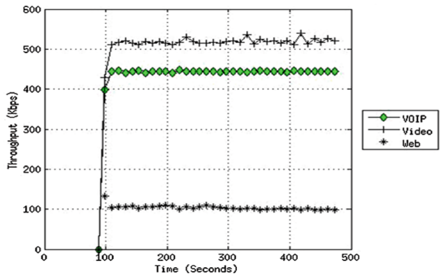

Fig. 11. Total Throughput (kbps) of NonGBR bearers with LTE_FICC

fairness among QCIs of NonGBR CoB. The throughput of video traffic with QCI-9 is higher than throughput of voice traffic with QCI-8 because the video sources have more traffic to send waiting in queues and thus take the additional share when resources are available in network.

3.5.2 Fair Resource Allocation Among Flows of Same QCIs of Non_GBR CoB

Figure 12 shows that when scheduling is performed using equal capacity sharing algorithm then the network cannot provide fairness among flows of same QCIs. Figure 13 shows modified round robin with LTE_FICC provide fairness within QCI as flows at same priority level are getting same amount of resources.

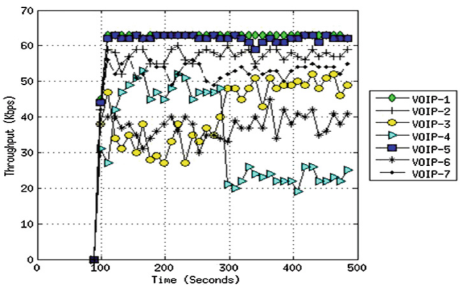

Fig. 12. Throughput (kbps) of NonGBR flows without LTE_FICC

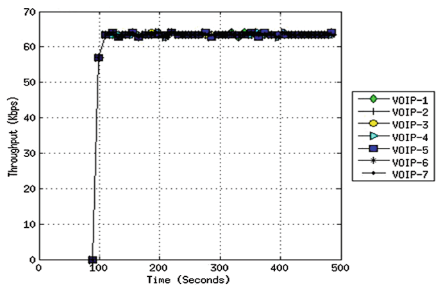

Fig. 13. Throughput (kbps) of NonGBR flows with LTE_FICC

3.6 Discussion on Results

The current simulations do not include additional features of LTE-Advanced including the extended bandwidth of 100 MHz and the enhanced MIMO techniques. Further results shall be presented in future based on the enhanced attributes of LTE_Advanced.

3.6.1 Consistency

Extensive simulations demonstrated that LTE_FICC is consistent in obtaining network performance in terms of fair resource allocation, high throughput, high link utilization and low queuing delay. It successfully maintains the queue length around the target operating point and results in small deviations in eNodeB output buffer queue length and in average queuing delay.

3.6.2 Fair Bandwidth Allocation

LTE_FICC accurately and consistently estimates the fair share of each CoB based on its respective QoS attributes and the queue length at the eNodeB output buffer. Consequently, along with modified round robin, it ensures that the packets that already occupy the buffer represent fair share of the connections of different QCIs within each CoB.

3.6.3 Bounded Queue Length

The overselling feature of LTE_FICC allows the unconstrained connections to take up the resources that cannot be utilized by the constrained connections. This allows LTE_FICC to successfully maintain the queue length around the target operating point and ensures that the output link is always utilized.

4 Conclusion

A new congestion control algorithm LTE_FICC is proposed, for both LTE and LTE-Advanced networks, and is demonstrated to perform effectively and efficiently. Instead of using thresholds to reduce the network congestion, LTE_FICC employs a target operating point. It maintains the network traffic around the target point, hence avoids congestion and loss at the eNodeB output buffer. The paper presented only a partial set of simulation results due to space limits. In the current implementation the target operating point was set manually. The future work includes setting the target point dynamically, at a level that is suitable for the network performance.

In future, we aim to propose an effective admission control algorithm that works together with the congestion control scheme to minimize the end to end delay of the network connections. We also intend to apply the proposed congestion control and the admission control schemes on the different scenarios of Australian National Broadband Network (NBN).

References

1. Cox, C.: An introduction to LTE: LTE, LTE-Advanced, SAE, and 4G Mobile Communications. Wiley, London (2012)
2. 3GPP 36.211, Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 11)

3. 3GPP 23.203, Technical Specification Group Services and System Aspects; Policy and charging control architecture (Release 12)
4. Vulkan, C., Heder, B.: Congestion control in evolved HSPA systems. In: 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring), pp. 1–6 (2011)
5. Kwan, R., et al.: On pre-emption and congestion control for LTE systems. In: 2010 IEEE 72nd Vehicular Technology Conference Fall (VTC 2010-Fall), pp. 1–5 (2010)
6. Qinlong, Q., et al.: Avoiding the evolved node B buffer overflow by using advertisement window control. In: 2011 11th International Symposium on Communications and Information Technologies (ISCIT), pp. 268–273 (2011)
7. Zolfaghari, A., Taheri, H.: Queue-aware scheduling and congestion control for LTE. In: 2012 18th IEEE International Conference on Networks (ICON), pp. 131–136 (2012)
8. Phan, H.T., Hoang, D.B.: FICC-DiffServ: A new QoS architecture supporting resources discovery, admission and congestion controls. In: Third International Conference on Information Technology and Applications (ICITA), pp. 710–715 (2005)
9. http://www.opnet.com (opnet modeler release 17.1.A)
10. 3GPP 36.213, Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures, Release 11
11. H.263 Video Traces, 7 July 2013. http://www2.tkn.tuberlin.de/research/trace/ltvt.html