Hierarchy Virtual Queue Based Flow Control in LTE/SAE

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Abstract—One of the key targets for LTE/SAE is 100Mbps peak data rate in downlink [1]. While compared to the lined data rate, the wireless data rate is still a bottleneck. This means if there is no flow control in aGW; packets will be buffered in eNB. While the buffer in eNB is limited, packets may be dropped. To reduce the harm to the performance of the TCP based application from packet loss, flow control is needed. There are huge amount of flows in one eNB and the rate varies from 10kbps to 100Mbps. In addition, the radio channel has the time-varying nature. All of them produce the challenge to the flow control of LTE/SAE. This paper proposes the hierarchy virtual queue (HVQ) based flow control mechanism to solve the problems. Simulation results show HVQ flow control requires fewer resources but produces better system performance.

Keywords—virtual queue; flow control; LTE; SAE

I. INTRODUCTION

The mobile broadband services of next generation are becoming available. Services such as high-speed internet access, mobile TV, fast interactive gaming will produce tremendous traffic in the future mobile networks. To make it happen, the Third Generation Partnership Project (3GPP) has launched the project LTE/SAE. The downlink peak data rate in LTE/SAE is 100Mbps, at the same time, there are still many low data rate application, such as AMR call, besides the radio channel has the time-varying nature. These issues challenge the flow control mechanism in LTE/SAE.

All kinds of flow control mechanisms have been studied for many years. Marc C. Necker and Andreas Weber studied the impact of Iub flow control on HSDPA system performance in [2]. Do J. Byun and John S. Baras studied adaptive virtual queue in satellite network in [3]. Qiu Yan Xia etc. studied dual virtual queues in WLAN in [4]. However, there is no effective and lightweight flow control mechanism available in LTE/SAE. This paper proposes the hierarchy virtual queue (HVQ) based flow control mechanism to reach this goal. The organization of the paper is in the following way: firstly, the LTE/SAE overview and the flow control alternatives are described; secondly, the proposed LTE/SAE model and flow control model are introduced. Thirdly, performance evaluation is presented. At last, the conclusion of the paper and possible future work is given.

A. LTE/SAE overview

LTE/SAE is an attempt to step into wireless broadband taken by cellular providers and equipment vendors.

LTE/SAE introduces evolved radio interface with major enhancement coming from the use of Orthogonal Frequency Division Multiplexing (OFDM) and multiple antenna techniques [5]. These technologies are already available on the market and employed in WiMAX as specified in IEEE 802.16 standard [6]. Along with the evolved radio interface, LTE/SAE specifies the evolution of network architecture. It is designed to be packet-based and contain less network elements which reduce protocol processing overhead, latency and network deployment costs. LTE/SAE is an evolved packet system which includes the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC).

The E-UTRAN consists of eNBs, providing the E-UTRAN user plane (PDCP/RLC/MAC PHY) and control plane (RRC) protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC, more specifically to the Mobility Management Entity (MME) by means of the S1-MME and to the Serving Gateway (S-GW) by means of the S1-U. The S1 interface supports a many-to-many relation between MMEs / S-GWs and eNBs. The E-UTRAN architecture is illustrated in Fig. 1 [7].

The main component of the SAE architecture is the EPC, also known as SAE Core. The EPC will serve as equivalent of GPRS networks via the MME, S-GW and PDN Gateway (P-GW) subcomponents [8] [9].

B. Flow control alternatives

There are basically two types of flow control mechanisms that could be applied: window or credit based and rate based.

Figure 1. E-UTRAN architecture
The window based flow control is used for instance by the TCP and the RLC protocols. The rate based method is used by the Available Bit Rate (ABR) service class in the ATM networks.

In the eNB case the window based flow control requires per-flow processing in the network processors. This is seen as a major drawback for its usage. Another difficult issue identified is how to efficiently distribute the credits when there are many flows sending but the available bandwidth is low. That is, to keep the delay bound it may not be possible to give even a single credit to each flow when the packet length is large. Thus the rate based method is seen more suitable. It uses a scaling factor which it sends to each MAC-d when the queue thresholds are crossed. The MAC-d instances then either reduce their sending rate or increase it, based on the scaling factor.

Another classification for flow control is: real queue based or virtual queue based.

In the real queue based method, the real queue length is monitored and flow control is sent based on it. Correspondingly in the virtual queue based method, the virtual queue length is monitored. The draining rate of the virtual queue is less than that of the real queue. Thus the effect of the flow control is that on average the real queue receives less traffic than the capacity. Consequently the delays caused by queuing are small in most cases caused only by the sending time of one packet, since the real queue length is short.

Implementing the real queue based flow control in certain type of network processors is difficult due to the very small amount of memory available for storing the necessary state information. Based on this, the virtual queue based method is the selected one, since it can be implemented in another part of the network processor where there is more memory available. It has the additional advantage that the difference between the draining rates of the real and virtual queues can be tuned. Thus the operator may choose whether he wants to put emphasis on small delays or on high bandwidth efficiency [10].

II. SYSTEM MODEL

The system model includes LTE/SAE network model, traffic model and flow control model. Network model and traffic model are described in detail in [11]. The difference is change the DropTail queue to DLQueue queue from server to aGW to support HVQ.

A. LTE/SAE network model

In the LTE/SAE network model, the following network elements are included (see Fig. 2):
- 1 server (provide HTTP, FTP and signaling services);
- 1 aGW (provide HTTP cache, flow control);
- 1 eNB (provide flow control information); and
- Many UEs (Support the four traffic classes).

B. LTE/SAE traffic model

When defining the UMTS QoS classes, also referred to as traffic classes, the restrictions and limitations of the air interface have to be taken into account. It is not reasonable to define complex mechanisms as have been in fixed networks due to different error characteristics of the air interface. The QoS mechanisms provided in the cellular network have to be robust and capable of providing reasonable QoS resolution [12]. There are four different traffic classes:
- Conversational class;
- Streaming class;
- Interactive class; and
- Background class.

The example of the application and simulation traffic of each traffic class are described in TABLE I.

C. Flow control model and its implementation

More accurate flow controls, better performance the system can get. However, the system’s resource, such as CPU and memory, is limited. Balance between the system performance and resource is needed. HVQ flow control provides the good solution to get the high ratio of performance over resource.

![Figure 2. LTE/SAE network model](image-url)
### TABLE I. TRAFFIC CLASSES IN LTE/SAE

<table>
<thead>
<tr>
<th>Traffic class (class id)</th>
<th>Example of the application</th>
<th>Simulation traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversational (0)</td>
<td>- Voice over IP</td>
<td>Session/RTP</td>
</tr>
<tr>
<td></td>
<td>- Video conferencing</td>
<td>- Session/RTPAgent</td>
</tr>
<tr>
<td></td>
<td>- Telephony speech</td>
<td>- Session/RTCPAgent</td>
</tr>
<tr>
<td>Streaming (1)</td>
<td>- Streaming video</td>
<td>- CBR/UdpAgent</td>
</tr>
<tr>
<td></td>
<td>- Streaming audio</td>
<td></td>
</tr>
<tr>
<td>Interactive (2)</td>
<td>- Web browsing</td>
<td>HTTP/TcpAgent</td>
</tr>
<tr>
<td></td>
<td>- Database retrieval</td>
<td>- HTTP/Client</td>
</tr>
<tr>
<td></td>
<td>- Server access</td>
<td>- HTTP/Cache</td>
</tr>
<tr>
<td></td>
<td>- Background download of</td>
<td>- HTTP/Server</td>
</tr>
<tr>
<td></td>
<td>emails, database,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>measurement records</td>
<td></td>
</tr>
<tr>
<td>Background (3)</td>
<td>- Background download of</td>
<td>FTP/TcpAgent</td>
</tr>
<tr>
<td></td>
<td>emails, database,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>measurement records</td>
<td></td>
</tr>
</tbody>
</table>

#### 1) Virtual queue based flow control

The basic principle of the virtual queue based flow control is shown in the following figure. A virtual queue is a fictitious queue with a capacity less than the actually available capacity. The motivation for using the virtual queue is that it provides advance warning of congestion.

![Virtual queue based flow control diagram](image)

For each real queue there is a corresponding virtual queue or a set of virtual queues, one for each differently treated traffic class. When packets arrive into the real queue, the virtual queue length is also updated by the length of the received packet. The draining rate of the virtual queue is $k \times C$ ($k \leq 1$), where $C$ is the draining rate of the real queue.

In [10] robustness and stability conditions for this kind of scheme compared with several types of schemes based on real queues have been analyzed and simulations have been performed. Based on the analysis and simulations it has been concluded that the virtual queue based method has one additional degree of freedom (selecting the value of $k$) compared to the real queue based methods. This makes it possible to maintain stability, reject large disturbances and to achieve good QoS, such as low queuing delay, at the same time, which is not possible with the real queue based methods.

In practice the implementation of the virtual queue is just a counter. The counter is incremented when data arrives into the real queue. It is decremented with a rate which is less than the available bandwidth for the real queue. Flow control is then sent based on the virtual queue length [10].

#### 2) HVQ based flow control

The proposed HVQ flow control uses three levels' flow control mechanism:
- UE flow control
- Cell flow control (not fully supported yet)
- eNB flow control

Flow control in each level is based on its own virtual queue and uses the independent flow control parameters. The actual rate $C$ is measured in the eNB with the following formula:

$$C_{n+1} = \alpha C_n + (1-\alpha)A_n$$

$C_{n+1}$ is the rate to be used in the air interface; $C_n$ is the rate used in the air interface in the last time; $A_n$ is the current measured rate in the air interface; $\alpha$ is the forget factor between 0 and 1. If $\alpha$ is 0, $C_{n+1} = A_n$, the history information is lost; If $\alpha$ is 1, $C_{n+1} = C_n$, only the history information is remembered. $A_n$ is measured by sent bytes divided by the measurement period. In the HVQ, the $C$ value to be used has to be multiplied by virtual queue factor $K$.

![HVQ based flow control diagram](image)

When the virtual queue length upper threshold reaches, the flow control information is send from air interface to the S1 interface. S1 interface will take the corresponding flow control actions. If the flow control information is about UE, the packets belong to the UE are blocked; if the flow control information is about cell, all the packets belong to the cell where the UE locates are blocked; if the flow control information is about the eNB, all the packets belong to the eNB where the UE locates are blocked. The blocking is cancelled when the lower threshold is triggered.

#### 3) Initial rate

The rate value used in the beginning (initial rate) needs to be determined in order not to cause congestion immediately and to arrive at a fair share of the bandwidth quickly enough. For non-real time traffic using half of the peak rate or preferably a configurable fraction of the peak rate (the nominal bearer rate, e.g. 128 kbps) appears a
suitable value. For real time traffic the initial rate could be the eNB given credits divided by 2 or using the credits directly, depending on how the eNB allocates the credits. Note that the sending rate shall never be allowed to exceed the eNB given credits.

4) Joint the flow control and scheduling together

If the QoS feature in the model is triggered, strict priority is used for scheduling. The packet to be sent is always in the flowing order class 0, class 1, class 2 and then class 3. Only when there is no packet in the higher priority queue, the packet in the lower priority queue is allowed to be sent; if the QoS feature in the model is not triggered, first-in-first-out (FIFO) is used to send the packet. The flow control is only valid to the background traffic whose classid is 3.

Random Early Detection (RED) algorithm [14] is used in the virtual queue for deciding when to send flow control. No packet dropping is used here to signal congestion, since the backward explicit congestion notification is used. The basic RED algorithm works as figure 5. There is a minimum threshold (min) below which no flow control is sent. When the virtual queue length exceeds the min threshold and is below the max threshold, flow control is sent with linearly increasing probability. The maximum probability max-p is an adjustable parameter, like the min and max parameters. Above the max threshold, flow control is sent with 100% probability.

\begin{figure}[h]
  \centering
  \includegraphics[width=0.5\textwidth]{red_function.png}
  \caption{Basic RED probability function}
\end{figure}

III. PERFORMANCE EVALUATION

This chapter describes the testing results of the HVQ based flow control mechanism. The performance evaluation focuses on total throughput, average delay and average jitter. The active users are the UEs which have the full traffic function, i.e. all traffic types are supported. In practice, several UEs can be mapped to one UE in the simulation environment. The profile of the testing is described in the TABLE II. There are a lot of parameters to be configured. Here only list some key parameters.

A. Throughput

When the active user number is less than 60, there is no big difference in the total throughput between normal scenario and HVQ scenarios. Increasing the active user number results in the buffer of eNB is overflow without the flow control mechanism. The dropping of the packets does harm the TCP performance a lot due to the TCP protocol’s congestion avoidance feature: the fast decrease of the congestion window. With the HVQ flow control, almost no packets will be dropped in the air interface and the S1 interface. The sender of the TCP can have a big sending window size which is the maximum value of congestion window and receiving window. The receiving window in the simulation environment is big enough, i.e. the UEs have enough power to receive the packets. In the simulation, the improvement reaches 28.71% when there are 100 active users if both HVQ_UE and HVQ_eNB are on. For more information, see Fig. 6.

B. Averaged delay

With the HVQ, the message queue length in the air interface is kept very small. Almost no packet dropping in the air interface and the S1 interface which leads to almost no retransmission in the TCP endpoints, which helps a lot in the average delay. Compare with the total throughput, the improvement of average delay is bigger. It reaches 34.37% when there are 100 active users and both HVQ_UE and HVQ_eNB are on. For more information, see Fig. 7. This improvement is very important for the delay sensitive applications, such as voice over IP in the LTE/SAE system.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Parameters & Values \\
\hline
Simulation time & 30 seconds \\
QoS feature & on \\
Multicast & on \\
\hline
Traffic profile & \\
Conversational & 12.2 kbps \\
Streaming & 128 kbps \\
Interactive & Average page size 10KiB \\
& Average page age 4 seconds \\
& Average page request 6 \\
Background & TCP segment size 512 bytes \\
\hline
Network profile & \\
Air interface & Bandwidth 10 Mbps \\
& Delay 2 ms \\
& Buffer 5K bytes \\
S1 interface & Bandwidth 100 Mbps \\
& Delay 2 ms \\
& Buffer 500K bytes \\
Core network & Bandwidth 1 Gbps \\
& Delay 2 ms \\
& Buffer 5M bytes \\
\hline
\end{tabular}
\caption{TESTING PROFILE}
\end{table}

\begin{figure}[h]
  \centering
  \includegraphics[width=0.5\textwidth]{throughput.png}
  \caption{Total throughput of the active users}
\end{figure}
C. Average jitter

The message queue length in the air interface is kept very small with the help of the HVQ based flow control. Almost no packet is dropped in the air interface and the S1 interface, which leads to almost no retransmission in the TCP endpoints, which helps a lot in the average jitter. Compare with the total throughput, the improvement of the HVQ based flow control mechanism guarantee the small average jitter, which is very vital for jitter sensitive application, such as video. For more information, see Fig. 8.

IV. CONCLUSION

From the testing results we can know HVQ based flow control mechanism improves the total throughput, decreases the average delay and average jitter of the LTE/SAE system. Due to this mechanism only controls the background traffic; it doesn’t decrease the higher priority traffic performance. More loaded the LTE/SAE system is, more improvement it can achieve. If the LTE/SAE system’s load is light, it is suggested to turn off the HVQ flow control mechanism to save the cost due to the improvement is limited. Another benefit of the HVQ flow control solution is flexibility. Customer can configure no flow control, one level, two levels or three levels’ flow control depends on the resource available. Next step is to implement the cell flow control (HVQ_cell) to gain more improvement. Also we can apply the HVQ flow control mechanism to other wireless-cum-wired networks. You can download the code and related documents about the LTE/SAE model and HVQ based flow control model from http://code.google.com/p/lte-model/.

REFERENCES