A framework for peer-to-peer video streaming over WiMax

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Abstract

Real-time peer-to-peer (P2P) streaming video traffic will constitute a significant proportion of future Internet traffic. With the availability of WiMAX, a large number of these peers will be ubiquitous and located on WiMAX based mobile nodes across the Internet. This chapter proposed a framework for providing quality of service (QoS) to the overlay P2P network over a WiMAX infrastructure. The work integrates traffic engineering and analytical based approach and has been validated with results from experiments.

Keywords: WiMAX; Peer-to-peer; ATM; QoS; queuing model; ASN-GW; mesh-pull;

1. Introduction

A significant proportion of streaming data on the Internet today is generated from different types of P2P real-time video streaming applications. These include P2P Television (P2PTV) and P2P webcasting. With the availability of increasing number of free and commercial grade P2P streaming applications (viz. TVPlayer, Zattoo, TVAnts, RayV, etc.), the volume of real-time P2P video traffic on the Internet will continue to increase. This type of traffic has significant different characteristics and QoS requirements than traditional Internet data traffic as well as from other non real-time P2P traffic. Unlike in a non P2P streaming application scenario, where a client will download stream only from a streaming media server, in this case a P2P client will also download the real-time stream from a number of other peers who themselves may be downloading from others depending on the P2P tree configuration. In order to ensure that the entire process is restricted to real-time, stringent delay control has to be provisioned by the underlying network infrastructure. A number of wireline technologies that have evolved over the years are available to provide strict QoS to meet these types of QoS challenges. However, with the growing popularity of ubiquitous and mobile computing, in the future these types of P2P streaming applications will also require support from mobile networking infrastructure to ensure that the same level QoS guarantees are available for mobile P2P streaming. In this context, the Worldwide Interoperability for Microwave Access (WiMAX) technology [1] is one of the main contenders to support this type of service. It has inherent multiservice capability to support broadband mobile services at up to 128 megabits per second (mbps) over a cell range of up to 30 miles radius. Future releases will...
support even higher data rates and coverage.

This paper outlines a model for providing mobile real-time P2P streaming services over the WiMAX network. The main focus of this paper is on presenting a framework for resource reservation for the P2P streams at the Access Service Network (ASN) Gateway component of a WiMAX network for providing the required level of QoS to the P2P applications. The paper assumes Asynchronous Transmission Mode (ATM) as the underlying layer-2 technology at the ASN level; however, the work could be easily extended for other technologies. Results presented from the simulation experiments have also been validated against an analytical model that has been developed in a separate but related piece of work.

The remainder of this paper is organized as follows: section 2 presents an overview of different types of real-time P2P streaming architectures focusing primarily on the mesh-pull system which is the most popular and is the system considered in this research; section 3 explains the general architecture and multiservice support available in a WiMAX network; section 4 presents the proposed framework for QoS provisioning for real-time P2P streams over a WiMAX infrastructure; section 5 presents a queuing model based solution for estimating the resource requirement for the QoS provisioning framework; section 6 presents the experiment results to validate the model; and section 7 makes the concluding remarks and suggestions for future work.

2. Overview of real-time P2P streaming systems

P2P streaming over the wireless networks faces a number of problems such as performance, reliability, scalability as well as the cost of communication. In order to address such issues various tools and techniques have been developed for P2P streaming. These include for example (i) streaming CDN (content delivery network) such as Akamai which are application level overlay networks that mainly target Internet applications in order to provide them with better QoS in sharing contents, and (ii) mesh-pull approaches such as CoolStreaming, PPLive [2], wherein peers pull streaming content from each other. In this paper we are interested in adapting the latter approach as it is believed to be more appropriate to the requirements of WiMAX infrastructure. Mesh-pull streaming systems follow simple system design and are more robust. Figure 1 shows a mesh-pull architecture of P2P live streaming [2].

In this architecture, peers (or streaming engines) have different upload capacities and they share bandwidth between each other. The original streaming contents (such as video) are first divided into chunks and are then made available for broadcast from the streaming server. All peers are able to access the streaming contents from the streaming server. Tracking server is used to keep track of the peers who are interested in accessing the streaming contents.

A peer first selects a required real-time streaming content, for example, a particular video. It then retrieves from the tracking server a list of other peers which are currently accessing the same contents or video. This peer then establishes a link those peers. All these peers then cooperate with each other in order to deliver/share the required content. Each peer also keeps a copy of the content (chunk of a video) in its cache and shares it with other peers that are accessing the same contents.

3. Architecture and QoS support in a WiMAX network
The WiMAX architecture defines a framework for end-to-end IP-based QoS-enabled multiservice for fixed and mobile users. The WiMAX network reference model is made of three logical components [Figure 2]. This includes the Mobile Station (MS), the Access Service Network (ASN) and the Connectivity Service Network (CSN). Each component is characterized by a set of related functionalities and are interconnected with other components by a clearly defined set of standardized interfaces. This allows smooth interoperability between different types of vendor equipments operating at different levels of the network.

The MS is generic mobile equipment providing connectivity between the mobile host and the ASN. The host could be a notebook, a WiMAX-enabled smart phone or a video camera with a WiMAX card for example. The MS is connected to the ASN via the R1 radio interface based on the IEEE 802.16 MAC and Physical layer (PHY) standards. The ASN consists of Base Stations (BS) and ASN Gateways (ASN-GW). Several BSs are connected to an ASN gateway via the R6 interface. This path is used to transport control messages from the ASN-GW and also for data from the CSN via the R3 interface. The ASN-GW is responsible for resource management between the base stations and supports ASN anchored mobility between the BSs connected to the same ASN-GW. ASN-GWs may also be inter-connected among themselves via the R4 interface for mobility and resource management. The work presented in this paper uses the ASN-GW as the main component for managing QoS among the real-time P2P streams. Several ASNs managed by a Network Access Provider (NAP) are connected to the CSN via the R3 interface. The CSN implements a range of layer 3 functionalities (viz. Dynamic Host Control Protocol (DHCP), Domain Name Service (DNS), IP mobility, user and device authentication and authorization via the Authentication Authorization Accounting (AAA) proxy/server, subscriber billing, etc.) and provides connectivity with other types of network such as the Internet, Public Switched Telephone Network (PSTN) and mobile networks. The MS is also virtually connected to both the Home and visited CSNs via the R2 logical interface that is used for overlay authentication, authorization and mobility control.

3.1. End-to-end QoS support in WiMAX

The WiMAX architecture facilitate end-to-end QoS that is necessary for real-time P2P streaming applications. The radio interface is based on the connection-oriented IEEE 802.16 protocol stack. It supports multiservice by providing customized QoS based on the requirement of the application. There are five different QoS classes in 802.16 to cater for different categories of application. These are the: Unsolicited Grant Service (UGS), Extended real-time Polling Service (ertPS), real-time Polling Service (rtPS), non real-time Polling Service (nrtPS) and Best Effort (BE). Among these the classes most suitable for real-time P2P streaming are the UGS, ertPS and rtPS. The key QoS parameters of these QoS classes are identical to that available in other QoS enabled networks such as Integrated services (intserv) or ATM [1]. These includes peak rate, maximum end-to-end delay and delay variation.

The remaining segment of a WiMAX network is typically wireline. These include the R3 interface between the
BS and the ASN-GW, the R4 interface in-between the ASN-GWs and the R3 interface between the ASN-GW and the CSN. QoS enabled wireline technologies have to be used to support end-to-end QoS across ASN and CSN. In addition, there has to be a well defined policy for mapping the QoS requirements from one type of network to another.

For example, for a P2P path it is possible that some of the peers are located on mobile nodes in the WiMAX network and the remaining peers outside the WiMAX domain. In this case, in the radio segment of the path, the connection could be set up using any suitable real-time 802.16 class and its associated set of QoS parameters. Across the ASN and CSN these sessions has to be mapped over other identical QoS-enabled multiservice technologies such as IP based Intserv paths or ATM network’s virtual circuits. In the case of Intserv, the 802.16 QoS class and its associated parameters could be mapped to an Intserv traffic class and its associated Traffic Specification (TSpec) parameters [1]. Similarly, in the case of ATM the QoS parameters could be mapped over an ATM QoS class and its associated traffic descriptors and QoS parameters [Table 1] [3]. Other types of IP based networks such as MPLS, Differentiated services network (Diffserv), IP tunnels, etc., could also be mapped appropriately and configured with an equivalent set of QoS parameters. In this paper, we have considered ATM as the technology for the ASN connectivity and IP tunneling for the CSN part.

Table 1. Mapping of IEEE 802.16 QoS parameters over Intserv and ATM

<table>
<thead>
<tr>
<th>Traffic Category</th>
<th>IEEE 802.16 class</th>
<th>ATM class</th>
<th>Intserv class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time P2P streaming video</td>
<td>UGS, etrPS, rtPS</td>
<td>Constant bit rate (CBR),</td>
<td>Guaranteed Service (GS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Real-time Variable Bit Rate (rt-VBR)</td>
<td></td>
</tr>
</tbody>
</table>

4. Model of the P2P overlay network

A P2P network may lay as an overlay network over the underlying WiMAX infrastructure. Peers sharing the same real-time stream may be distributed both within the WiMAX network and as well as outside it. Even within the same WiMAX network, peers may be scattered across different ASN and managed by different ASN-GWs. In this context, the ASN-GW acts as the main component for resource management and QoS provisioning for the real-time peers being served by it. It has to efficiently schedule network resources such as bandwidth and buffer to provide QoS guarantees in terms of bandwidth, delay, jitter and loss for the P2P streams. In the proposed model for the

Fig. 3. Grouping P2P traffic using CBQ

ASN-GW, peers sharing the same real-time content are grouped into classes and serviced at the class level. This approach is logical since different sections of the same content will still share the same inherent stream specific
characteristics viz. packet length distribution and inter-arrival time and therefore could be served with the same level of QoS. Multicasting based approach could make the solution simpler; however because of the limited availability of end-to-end multicast support and the overhead associated with it [4], it has not been considered. The peer streams are grouped using Class Based Queuing (CBQ) and resources are allocated to the class. Therefore different peer set sharing different real-time content are grouped into different classes and allocated different level of resources based on the characteristics of the original stream and the number of peers. Other prominent resource management schemes such as Weighted Fair Queuing (WFQ) and sorted priority schemes are not suitable in this context as they either provide very conservative estimate or suffer from scalability problems. In contrast, CBQ provides strict bandwidth portioning between the classes and is relatively simple to implement. As mentioned earlier, in this paper the connectivity between the ASN-GW and the BS and also in-between the ASN-GWs has been considered to be based on ATM virtual circuits (VCs) where each of the CBQ classes in the ASN-GW is mapped on to a separate ATM CBR VC. The QoS parameters of the circuit are configured based on the QoS requirements of the CBQ class. The model presented in this paper could be adapted for rt-VBR type of ATM circuits or to other types of networking technologies.

4.1. Architecture of the P2P QoS unit at the ASN-GW

The internal structure of the ASN-GW is divided into two horizontal and three vertical planes [Fig. 4]. The two horizontal planes are the control and data planes and they provide clear distinction between control and data transfer operations. The vertical planes are the Peer-grouping, QoS-mapping and ATM-interface planes.

Fig. 4. Framework for P2P QoS provisioning at the ASN-GW

4.1.1. The Control Plane

The control plane is responsible for grouping of peer streams and management of ATM VCs. It is divided into three components:

The Traffic Aggregator is responsible for combining the traffic specification of the peers. Here, the traffic specification of the flows is composed of the first two moments of packet inter-arrival time and packet length distribution ($\{\bar{a}, C_a\}$, $\{\bar{l}, C_l\}$). Although streams from to the same peer group will have identical traffic specification, however the aggregated inter-arrival time characteristics will change based on the number of peers in the class. The traffic parameters are merged and are passed to the QoS estimation engine module for predicting the bandwidth requirement of the ATM VC.

The Prediction Engine uses the first two moments of inter-arrival time and packet length distribution as its input parameters and predicts the response time of the system at different utilization level based on the GE/GE/1 model.
A discussion on the queuing model and its performance has been presented in the next section. The queuing models can predict the response time delay for a particular service rate, based on the above traffic descriptor parameters. However, the stream parameters will include the delay requirement for the stream as part of its QoS parameters, and the ASN-GW will be required to provision the appropriate ATM VC rate to guarantee that delay requirement. However, the equation of the queuing model [3][5] cannot be inverted to find the corresponding value of the utilization (and therefore the service rate) that satisfies the delay parameter. Therefore a lookup table has been created based on the equation of the queuing model, which is thereby used by the Prediction Engine.

The lookup table stores the corresponding value of the utilization ($\rho$) for different combination of the parameters $C_a^2$, $C_S^2$, and $D_n$ where:

- $C_a^2$ = SCV of the inter-arrival time of packets,
- $C_S^2$ = SCV of the service time, and
- $D_n$ = 99-percentile delay normalised to the arrival rate value with $a_i = 1$ such that $D_n = \text{Desired delay} \over \text{Inter-arrival time (} a_i \text{)}$.

Under this circumstance, the utilization ($\rho$) is equal to the mean service time ($S$). Moreover, since the service time distribution is proportional to the packet length distribution, therefore $C_S^2 = C_i^2$.

Now, based on the traffic descriptor parameters $a_i, C_a^2, l, C_i^2$ and $D$, the corresponding value of $\rho$ can be evaluated. At the next stage, the required service rate ($R$) for the class is calculated based on the following equation:

$$R = \frac{53 \times l}{48 \times \rho \times a_i}, \quad (1)$$

When a new peer attempts to join a class, its traffic parameters are used to update the aggregated traffic specification of the class. The updated specification is then used by the Prediction engine to estimate the new rate requirement for the VC by referencing the lookup table (Table 2).

<table>
<thead>
<tr>
<th>$C_a^2$</th>
<th>$C_S^2$</th>
<th>$D_n$</th>
<th>$\rho$</th>
<th>$R_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.1</td>
<td>0.615339</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td>1.0</td>
<td>0.1</td>
<td>0.641145</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>1.0</td>
<td>0.2</td>
<td>2.397664</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>1.0</td>
<td>0.2</td>
<td>2.449153</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>1.0</td>
<td>0.4</td>
<td>1.375782</td>
<td>0.35</td>
<td>0.1</td>
</tr>
<tr>
<td>1.0</td>
<td>0.4</td>
<td>1.413020</td>
<td>0.35</td>
<td>0.2</td>
</tr>
<tr>
<td>3.0</td>
<td>0.1</td>
<td>2.244535</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td>3.0</td>
<td>0.1</td>
<td>2.269753</td>
<td>0.25</td>
<td>0.2</td>
</tr>
</tbody>
</table>

After a peer stream is accepted, control is passed to the Resource Manager for updating the resources to accommodate the new stream. This research is focused only on the bandwidth resource. However, it could be extended to include buffer, processor cycles and other resources. The CBQ rate controllers of the continuous media classes provides strict bandwidth partitioning between the classes and ensures that existing continuous media classes are not effected in the process (Fig. 3).

4.1.2. The Data Plane

Once a new peer is accepted in a class by the control plane, all data packets in the new stream are processed by the data plane. The data plane is divided into three components; the forwarding engine, the AAL encapsulation
The Forwarding Engine has two main components. Packets arriving at the ingress point from the CSN are first classified by a classifier module. In the case of raw IP traffic, classification could be based on combination of source and destination IP address and transport layer port identifiers (for IPv4) or on the flow-label and the Class fields (for IPv6). Traffic arriving from Differentiated services (diffserv) network, Multiprotocol Label Switching (MPLS) network, IP or GRE tunnels could be classified based on Diffserv Code Point (DSCP), MPLS label, VLAN tag or GRE key respectively.

The classified traffic is then metered to compare the traffic profile of the stream with the original traffic characteristic. Out of profile traffic may either be dropped or forwarded on a best-effort basis using a UBR VC.

At the next stage, the packets are forwarded into the Encapsulation module where the packets are encapsulated into AAL5 payload. AAL5 is used as the adaptation layer protocol in this model because of its low overhead, simplicity and wide availability across ATM platforms. The AAL segments are then passed to the ATM interface where they are fragmented into ATM cells and enqueued in the shaping buffer. The queues are then served by the CBQ scheduler over the ATM VC into the ASN.

5. Estimating the rate of a P2P class

Determining the rate to be allocated to the P2P class is an integral part of the flow mapping process. The peak rate needed to meet the QoS requirements is determined from the response time distribution of a queuing model. The queuing model is one of a system with “Pure Limited Server Vacations” in particular a GE/GE/1 queue with GE-type cycle times (cycle = service + vacation) and single vacation. A solution for the response time distribution of this queuing system has recently been developed and validated in a separate piece of work, and the derivation of this solution is outside the scope of this paper.

The parameters used by this model are: the arrival rate of the P2P streaming packets \( \lambda \); the squared coefficient of variation (SVC) of the inter-arrival times \( C_a^2 \); the average packet length \( \bar{L} \); and the SCV of packet lengths \( C_l^2 \). The output QoS parameter from the model is some high percentile (e.g. 99%) of response time delay. The parameters of the peers are first aggregated by a merging process [3] before the response time is calculated by the queuing model.

6. Validation of the ASN-GW model

The CBQ model (Fig. 3) presents the core operation of the data plane of the P2P provisioning model of the ASN-GW (Fig. 4). A simulation of the CBQ model was built using the OPNET network simulator. Two peer classes P1 and P2 were set-up with three and six peers in each group respectively. The packet length characteristics of the two streaming sources were taken from two different MPEG-4 streams and are presented below in Table 3.

Table 3. P2P stream characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P1</th>
<th>P2</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. packet length</td>
<td>8024 bits</td>
<td>219488 bits</td>
<td>85600 bits</td>
</tr>
<tr>
<td>( a = \frac{1}{\lambda} )</td>
<td>5000 bits</td>
<td>79880 bits</td>
<td>8000 bits</td>
</tr>
<tr>
<td>( C_l^2 )</td>
<td>0.25</td>
<td>0.23</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Streams belonging to the same peer group are considered to have the same mean inter-arrival time; however the SCV is different since each individual stream may suffer different level of delay and jitter. The inter-arrival times of the P2P streams were based on GE distribution. This type of distribution was considered to be more realistic representation of continuous media flow, it being more flexible than, says Poisson or negative exponential distribution. The GE distribution also allows zero inter-arrival time, which is useful for depicting bursty arrival. The GE distribution also allows variability of inter-arrival times, i.e. experiments could be conducted with a range of...
SCV values. Data traffic was only used as background load in the experiments and their packet lengths were generated from an exponential distribution with an arbitrarily chosen mean.

6.1. Results

The results for the P2P sources from some of the runs are presented below and compared against the analytical model. In all the experiments, the upper bound on the response time of the queue has been presented by showing the 99%-tile delay. By considering the upper bound it can be ensured that any resource dimensioning based on these parameters will be optimal for the worst-case scenarios. Each of the simulation was run ten times independently with identical set-up but different seed values, and the 95% confidence intervals of the results have been presented.

Fig. 5. Comparison of the response time for the peer class P1 and P2

The results demonstrate that the delay experienced by the two peer classes is identical to the analytical results. As the utilization factor of the queue increases (i.e. the service rate decreases), the queuing delay becomes larger and the corresponding response time of the queueing system also increases. This can be seen in the case of both the peer classes. In addition, the estimated delay for peer class P1 is relatively more conservative than for peer class P2. This trend has been identical across several experiments where the number of peers in a class has been small. This is not a significant factor as an ASN-GW will typically be serving several peers nodes within its access network.

7. Conclusion

This paper presented a framework for delivering real-time P2P streaming service over a WiMAX network. A detailed architecture of the ASN-GW whose operation is based on the combination of engineering and analytical techniques was illustrated. The work demonstrated the effectiveness of using probabilistic solution in dimensioning the resource requirement of a network.

References

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