A Model on The Differentiated Service with Packet Scheduling in Multi-hop Wireless Networks*

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Abstract

For the purpose of ubiquitous networking, the multi-hop wireless networks have become a vital extension to wired networks. It is an important issue on how to provide the differentiated service for multimedia data which has widespread applications in the multi-hop wireless networks and strict QoS demands. Nowadays, most researches on differentiated service in wireless networks concentrate on the adjustment of contending window size without considering the difference of the communication state in each local network node. Some differentiated service mechanisms risk the excessive resource allocation and complicated signaling exchange procedure. For these cases, this paper proposes a differentiated service model MDSPH applied in multi-hop wireless networks, which takes the end-to-end data transmission delay as the analyzed object. Based on the data packet hierarchy queue scheduling and the dynamic bandwidth resource allocation in multi-queue scheduling, the data transmission delay and rate for the high service priority data are guaranteed in multi-hop wireless networks to the utmost extent. Meanwhile, the service opportunity for the low service priority data is also obtained in terms of round-robin scheduling rule and this ensures fairness in providing service guarantee for different network data. Theoretic analysis and simulation test show the validity of the model.

Keywords: Differentiated Service; Packet Scheduling; Resource Allocation

1 Introduction

With the continuous development of wireless network applications, the need for the transmission of voice, video and other media data increases rapidly and the media data has a strict requirement on the data transmission delay, bandwidth and other QoS parameters. Therefore, it is a primary issue to provide the QoS guarantee with differentiated service based on the service requirements...
of application data and the specific features of the wireless networks. And the paper proposes the differentiated service model for multi-hop wireless networks, MDSPH (The Model on the Differentiated Service with Packet Hierarchy-queue-scheduling in Wireless Networks), based on the packet hierarchy queue scheduling and the dynamic network resource allocation.

Nowadays, the relevant researches on the differentiated service in wireless networks have focused on the following aspects. Papers [1], [2], [3] and [4] discuss the differentiated service in wireless networks based on the adjustment of nodes’ channel resource access parameters. Papers [5], [6] and [7] propose some packet scheduling algorithms on differentiated service based on pre-defined services in IEEE802.16. And based on the DiffServ and MPLS protocols in IP networks, papers [8], [9], [10] and [11] put forward the differentiated service mechanisms for multi-hop wireless networks with consideration of the data transmission routing optimization and the network node resource detection and assignment. To some extent, the aforementioned researches provide a good exploration on the differentiated service in wireless networks. But they lack the real-time dynamic descriptions in time-variant multi-hop wireless networks and consider the fact less that in the multi-hop wireless networks, nodes in different locations have different channel resource aware states. Besides, the signaling interactive mechanisms and relevant extending information for packet structure in some mechanisms are too complex to be used for the multi-hop wireless networks.

The MDSPH exhibits three important aspects: first, the model mainly focuses on providing the guarantee for data transmission delay and bandwidth of the each local network node in multi-hop wireless networks, which makes the model bear the characteristics of distribution applicability and strong robustness in unpredictable changes of wireless links. Second, the scheduling operation based on the current delay state of data transmission can enable network data transmission statelessness to a large extent and reduce the extra signaling data transmission. Third, the available bandwidth resource in each wireless multi-hop network node is prone to be influenced by the channel contending access of neighboring nodes and their mobility. As a result, it is essential to introduce dynamic bandwidth resource assignment relevant to different network data in scheduling. Thus the transmission of data with high priority can be guaranteed and transmission delay can be decreased.

This paper is organized as follows. In section 2, the environment of the multi-hop wireless networks and MDSPH are described. Section 3 gives a complete description and analysis on MDSPH and its components in detail, followed by the model’s performance evaluations in section 4 and the detailed simulation experiment is carried out in section 5. And the last section wraps up the paper.

2 Network Model and Problem Description

Suppose that the nodes in WLAN communicate in the same mode as that in the Ad hoc network nodes and the existing APs (Access Points) act as the Internet gateway for all mobile user nodes. The remote mobile user nodes beyond AP’s single-hop range communicate by the multi-hop paths according to the preselected routing protocol. And in this wireless multi-hop communication, the different application data requires different transmission service, especially the transmission delay, which is shown in three aspects.

1) when the data flow transmits in some specific path $R_f(t)$ (where $t$ is measuring time for net-
work status), on condition that the single-hop data transmission delay of packets in is within the maximal accepted range, then the end-to-end packet transmission delay should satisfy equation (1):

\[
\min \sum_{s=1}^{N} \max((t_s/t_s') - 1, 0) \quad (P(t_s^h > (t_s'/n)) \leq \delta_s)
\]

Equation (1) shows the object function on delay guarantee related to any single-hop data transmission in every multi-hop transmission path, where \(t_s, t_s'\) and \(t_s^h\) are the real end-to-end data transmission delay, the required end-to-end data transmission delay in service guarantee and the hop-by-hop data transmission delay respectively. And \(\delta_s\) is the accepted threshold for \(s\) and \(n\), \(N\) are the hop-count in transmitting path and the number of \(s\) with the required delay guarantee respectively.

2) After receiving the packets in \(s\), the node \(k\) in \(R_f(t)\) should do the operation \(P(t)\) (where \(P(t)\) denotes one service guarantee rule described in MDSPH) accordingly based on the current data transmission delay. In multi-hop WLAN, because there exists the channel resource contending access among neighboring nodes, the available bandwidth of each node is influenced by its data transmission state at different time and this results in unstable data transmission rate. Moreover, the mobility of some nodes makes data transmission paths unstable. All these have a great impact on the guarantee for network data transmission delay. Therefore, in order to solve the above issues, it is important to introduce the procedure on dynamic bandwidth resource assignment based on the weight of scheduling queue in MDSPH, and this can not only guarantee the required data transmission rate for the high priority network data, but also mitigate the burst data transmission to some extent.

3) In order to ensure the fairness of different types of data in scheduling, the model introduces round-robin queue scheduling rule, but the scheduling time for each queue is different in scheduling period, which relies on the weight of the specific queue. This procedure satisfies equation (2),

\[
\left| \frac{W_{s_1}(t_1, t_2)}{p_{s_1}} - \frac{W_{s_2}(t_1, t_2)}{p_{s_2}} \right| = 0
\]

Equation (2) describes the fairness in providing differentiated service for network data with different priority. And \(W_{s_i}(t_1, t_2)\) is the guaranteed service received by data flow \(s_i\) in \((t_1, t_2]\), it satisfies \(W_{s_i}(t_1, t_2) \geq r_s(t_2 - t_1 - \tau_s)\) (where \(r_s\) is the average packet transmission rate and \(\tau_s\) is the starting time of \(s\) in \((t_1, t_2]\)). \(p_{s_i}\) denotes the service priority corresponding to \(s_i\).

3 Description of Differentiated Service Model Based on Packet Hierarchy Scheduling

3.1 Description of the service model

The packet scheduling mechanism in MDSPH consists of two levels. First, the mechanism scatters the packets into three different queues (stream classification), the PS (Premium Service) queue, AS (Assured Service) queue and BE (Best Effort service) queue, which are formed according to the CoS (Class of Service) label in every packet. Suppose that the queue type here is set to be consistent with the service definition in DiffServ model (this provides the basis for network interconnection access between wireless mobile nodes and IP networks, and the service classification
can be extended according to the specific requirements in the discussed service model). In the queue scheduling cycle, every queue is scheduled in a round-robin way and the scheduling time is in direct proportion to the queue weight, which both ensures fairness and provides differentiated service for the different types of network data. And in order to reduce the adverse influence on the high-priority data transmission, which is from the unpredictable bandwidth resource changing of nodes in multi-hop wireless networks, the model dynamically distributes the bandwidth resources to the queue according to its weight. This ensures the required bandwidth resource for high service priority data in the higher-weight queues to the utmost extent.

Second, the model takes the current cumulative delay of the packet $D_i$ as the main benchmark for the second scheduling level. Based on $p_i = t_i - D_i$, the scheduling is described that the smaller $p_i$ is, the higher the scheduling priority of packet $i$ is and conversely the lower the scheduling priority of the packet is. And such per-hop packet priority scheduling further ensures the differentiated service for different network data in multi-hop wireless networks.

### 3.2 Scheduling model based on data service priority

#### 3.2.1 Description of dynamic scheduling queue bandwidth resources allocation

The data with three different service levels (deterministic service, statistical service and best-effort service) corresponds to the different queue $q_i$ which satisfies the relation $Q: \{q_i | w_i < w_{i+1}, i = 1, 2, 3\}$ (where $w_i$ is the weight of $q_i$ and satisfies $\sum_{i=1}^{3} w_i = 1$), and assume that $q_i$ corresponds to three types of network data respectively, namely, the real-time voice data, the video and Web streaming data (Telnet, Web browsing data) and the file transfer data (mail-transfer data). For $q_i$ with different $w_i$, the model schedules $q_i$ in turns according to $w_i$. And in scheduling, each $q_i$ is dynamically allocated the bandwidth resource which satisfies $B_i / w_i \approx B_i / w_1$, where $B_i$ is the maximal amount of the allocated bandwidth resource in $q_i$ and it describes the maximal data transmission rate in $q_i$ within the $l$th scheduling cycle $T_i$. The packets are scheduled from $q_i$ corresponding to the larger $w_i$ in the time $t_i$ (where $t_i$ satisfies $t_i = w_j * T$ and the data transmission rate can reach the maximum $B_i$ in scheduling). After the time of $t_i$, the mechanism schedules data from $q_{i-1}$ with $w_{i-1} < w_i$ in the time $t_{i-1}$ and the data transmission rate can reach the maximum $B_{i-1}$. The process repeats till the end of the scheduling cycle $T_i$ and then the scheduling turns to the new cycle $T_{i+1}$. In the scheduling, if $q_j$ is empty or all the data in it is scheduled in the time $t_j$, the scheduling turns to the queue $q_{j+1}$ with the smaller weight $w_{j-1}$. And when all the data in $q_i$ with the lowest service priority is scheduled or the $q_1$ is empty, the current scheduling cycle $T_i$ ends beforehand and the scheduling returns to $q_i$ with the largest $w_i$ to start a new queue scheduling.

In the first scheduling level, there exist two problems: In order to maintain the stability of data service parameters within the cycle, the model sets the scheduling cycle $T_i$ as the longest transmission time of the data flow in the queue with a higher weight (There is also the heuristic setting based on other criteria). The instability of the wireless links results in the instability of data transmission. Therefore, how to dynamically adjust the service parameters (bandwidth) of the queue in scheduling is an important issue to provide the service guarantee in multi-hop wireless networks. According to the service parameters statistics (bandwidth and packet loss rate) in the scheduled time of the queue, MDSPH updates the service parameters of each queue in real time at the end of every scheduling cycle. The adjustment procedure is described as follows.
Step1: For \( q_i \) with storing the high service priority data, the mechanism counts the request bandwidth \( B^{i}_{\text{total}}(t^{i}_l) \) (where \( B^{i}_{\text{total}}(t^{i}_l) = \sum_{s \in \Gamma_i} B^{i}_{s \text{Req}}(t^{i}_l) \)), \( \Gamma_i \) is the set of \( s \) in \( q_i \) for all \( s \) in \( q \). If \( B^{i}_{\text{total}}(t^{i}_l) \) satisfies \( \Delta B^{i}_{c}(t^{i}_l) \geq B^{i}_{th} \) (where \( \Delta B^{i}_{c}(t^{i}_l) = B^{i}_{c}(t^{i}_l) - B^{i}_{\text{total}}(t^{i}_l) \) and \( \Delta B^{i}_{c}(t^{i}_l) > 0 \) the threshold \( B^{i}_{th} \) is set according to the properties and numbers of \( s \) in current networks, and \( B^{i}_{c}(t^{i}_l) \) is the pre-allocated bandwidth for \( q_i \) in the current \( T_i \), the scheduling mechanism adjusts the bandwidth for \( q_i \) to \( B^{i}_{c}(t^{i+1}_i) = B^{i}_{c}(t^{i}_l) - (\Delta B^{i}_{c}(t^{i}_l)/\mu) \) (where \( \mu \) reduces the jitter in adjustment and is set based on the network traffic-load, and \( \mu = 2 \) is set in the paper) at the end of the current \( T_i \). Meanwhile, the mechanism releases the bandwidth \( \Delta B^{i}_{c}(t^{i}_l) - (\Delta B^{i}_{c}(t^{i}_l)/\mu) \) related to \( q_i \).

Step2: If the node receives more \( s \) with a higher service priority in a certain \( T_i \), and the \( B^{i}_{\text{total}}(t^{i}_l) \) satisfies \( B^{i}_{c}(t^{i}_l) \leq B^{i}_{\text{total}}(t^{i}_l) \leq B^{i}_{c}(t^{i}_l) + B^{i}_{\text{free}}(t^{i}_l) \) (where \( B^{i}_{\text{free}}(t^{i}_l) \) is the current available bandwidth of the node \( i \), the mechanism adjusts the bandwidth for \( q_i \) to \( B^{i}_{c}(t^{i+1}_i) = B^{i}_{c}(t^{i}_l) + (B^{i}_{\text{total}}(t^{i}_l) - B^{i}_{c}(t^{i}_l)) \) at the end of the current \( T_i \). And assumes that the admission control mechanism in nodes avoids the state of \( B^{i}_{c}(t^{i}_l) + B^{i}_{\text{free}}(t^{i}_l) \leq B^{i}_{\text{total}}(t^{i}_l) \) beforehand, which reduces the invalid data transmission in insufficient bandwidth resource.

### 3.2.2 Description of the single-queue packet scheduling

In the second scheduling level, the model schedules packets from \( q_i \) based on \( D^{i}_c \). In scheduling, the model sets the packet scheduling order based on the function \( o_i(D^{i}_c) \) (where \( o_i(D^{i}_c) \) is the monotone decreasing function with \( D^{i}_c \)). For simplifying the computation, the model sets \( o_i(D^{i}_c) = 1/D^{i}_c \). And the packet with \( \min\{o_i(D^{i}_c)\} \) in \( q_i \) is given the higher scheduling priority, and \( D^{i}_c \) can be obtained from the time-stamp field in each packet header. In this way, the model decreases \( D^{i}_c \) through the process to reduce the per-hop data transmission delay in every data packet to the utmost extent.

### 4 Performance Analysis of MDSPH

MDSPH improves the whole network system performance through the improvement on data transmission performance of local networks. The model takes the reduction of network data transmission delay as the analyzed object and analyzes the state of data transmission for high service priority data in queue scheduling. And two aspects are analyzed in details. First, suppose that the network node receives the packet with service level \( j \) before receiving the packet \( p_i \) with service level \( i (j < i) \). If the scheduling adopts the FIFO rule, \( p_i \) will be scheduled at least after the \( q_j \) queues are scheduled (many queues constitute a single queue in series). But if MDSPH is adopted in scheduling, \( p_i \) will be scheduled before at least the number of \( \sum_{k=j}^{i-1} L_k \) (where \( L_k \) is the length of queue \( q_k \)) packets are scheduled, and so, the packet transmission delay reduction \( \Delta \tau \) is at least \( \sum_{k=j-1}^{i-1} L_k/r_k \) (where \( r_k \) is the data transmission rate in \( q_k \) and set to the average value \( \bar{r}_k \) which satisfies \( \bar{r}_k \approx B_k \), and \( B_k \) is the allocated bandwidth resource for \( q_k \)). Second, considering the relation between the end-to-end data transmission delay \( D \) and data transmission rate \( r \), that is \( D(\sigma, r) = (\sigma + \sum_{l \in p} c_{l})/r + \sum_{l \in p} D_{l} \) (where \( D(\sigma, r) \) and \( D_{l} \) are the end-to-end data transmission delay and the per-hop link data transmission delay in data transmission path \( P \) respectively. \( \sigma \) and \( c_{l} \) are the data burst traffic in link \( l \) and the maximal packet length.). Based on the above
analysis, the reduction on data transmission delay $\Delta\tau$ in local network nodes decreases $D_t$, in scheduling. The dynamic resource allocation based on the scale of weight-bandwidth ensures $r$ for the high service priority data. And according to the function $D(\sigma, r)$, the end-to-end data transmission delay of high service priority data is guaranteed by the reliable data transmission rate in MDSPH.

As a service guarantee model used in multi-hop wireless networks, the dynamic adaptability of MDSPH is reflected in the dynamic bandwidth resource allocation for scheduling queue and the service guarantee of the per-hop data transmission delay. And all these are limited to local node computing and introduce signaling detection information on network state to the minimal extent. This not only enables the model to have a better distribution feature in information processing, but also reduces network communication overhead to some extent. And also, the scheduling mode resembling round-robin mode for all queues ensures the transmission fairness for various network data, which is a significant advantage of the model.

5 Experiments

5.1 Experimental setup

In the ns-2 simulation environment, 20 nodes are set to moving in an area of 1000m×1000m (the maximum speed is 10m/s, and the average pause time is 10s), and the communication radius for wireless network nodes is set to 250m and the MAC protocol adopts 802.11. The experiment takes CBR flow to simulate real-time data (high service priority data), with its packet sending rate 20packet/s and packet length 512Byte. The real-time data with two different service levels are simulated in the experiment, 1) voice data, with the highest service priority and the maximal weight of the queue. The experiment takes Pareto on/off flow to simulate it. 2) video data, with the service priority and weight only secondary to that of voice data. The experiment takes Exponential on/off flow to simulate it. And the experiment takes Web data flow in the form of a TCP connection to simulate the data with the lowest service priority. The simulation time is 300s.

Two major reference and comparison models are introduced in the experiment, the SWAN [11] and the CWmin model [1,3]. The major analyzed network performance indicators are as follows. 1) network throughput, manifested mainly in two aspects. One is comparative analysis of the data throughput in different differentiated service models for the same type of data. The other is the throughput state analysis of various data in network using MDSPH. 2) average data transmission delay. Two aspects are also considered to analyze the average end-to-end data transmission delay, the data transmission delay for the same type of data is analyzed in applying different service models and the data transmission delay for the different types of data is analyzed in MDSPH.

5.2 Experimental results

To obtain the accurate experimental results, the simulation results take the form of the statistics. That is, the experiment is repeated 10 times under the same network parameters settings, and the average value of the data is taken for the final results.

Fig.1 describes the network throughput of various data in networks that adopt two different
differentiated service models. Figure (a) shows the network throughput of three different service priority data in networks that use the CWmin model. It shows that with the increase of detecting time, the two high-priority real-time data illustrate a higher network throughput in using the differentiated service mechanism. Figure (b) shows the network throughput of various data in networks that use MDSPH service model. The data of two subfigures in Fig.1 illustrates that MDSPH can quickly enhance the network throughput of high service priority data and maintain the data in a stable throughput state. The reason lies in that MDSPH provides the bandwidth resource guarantee for the high service priority data, which ensures the data transmission rate for high service priority data and hence guarantees its network throughput.

Fig. 1: Performance comparison of network throughput in different models

Fig. 2: Transmission delay comparison of network data in different models

Fig. 2 shows the average end-to-end data transmission delay of various data in networks which adopt different differentiated service models. Figure (a) shows the average end-to-end data transmission delay of the same type of data(real-time Video data) in networks that use different service models, with x coordinate as the network load (the number of data flows). Figure (b) shows the delay of the data with three different service priority levels in networks which applies MDSPH. Fig.2 shows that MDSPH has a greater advantage in providing guarantee on data transmission delay because the model has a rule on packet priority scheduling based on single-hop data transmission delay.
6 Conclusion

It is an important issue to study the differentiated service in multi-hop wireless networks. Different from the static differentiated service model in IP networks, the paper makes a research on the differentiated service model in wireless multi-hop network based on packet hierarchy queue scheduling structure and the main feature in the model is that the unpredictable time-variant network communication is fully considered based on the real-time dynamic service parameter adjustment. The model studies the network service guarantee from the points of packet scheduling strategy in reducing data transmission delay and bandwidth resource allocation in improving data transmission rate. Based on the above two points, the delay guarantee for the higher service priority data is provided in multi-hop wireless networks. The following researches will focus on the end-to-end service description and mapping in multi-hop wireless networks based on time-variant network status to further perfect the differentiated service mechanism in wireless networks.

References