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An Adaptive QoS Model in Wireless Ad Hoc Networks

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Abstract: How to get quality of service (QoS) support in the MAC layer is a hot topic in wireless ad hoc network (MANET). In this paper, a novel adaptive QoS model is presented in MANET, and its feasibility and reliability is analyzed and verified. Compared with traditional SWAN model, the proposed approach is improved by differentiated services in MAC layer in order to achieve high control rate of low-priority transactions. The simulations of the presented model are carried out and the results show that can improve the bandwidth utilization and increase the network throughput, as well as reduce transmission delay in MANET.

Keywords: Wireless ad hoc networks; QoS; adaptive model; MAC

1 Introduction

Wireless Ad Hoc Networks is a special kind of wireless communication network, which is a multi-hop autonomous system composed by a plurality of nodes with a wireless transceiver device. The node in the network has the function as both host and router [1].Over the past decade, MANET is increasingly becoming a hot research field in computer networking and wireless communications [2-4].Since MANET doesn't require fixed infrastructure and has a strong invulnerability, it has a high application value. The main characteristics of MANET include sharing radio channel, high bit error rate, multi-hop communications and dynamic topology. In this context, it is a great challenge to provide QoS support [5]. On the other hand, although the MANET protocol stack has the similarity with the Internet protocol stack, the related protocols cannot be directly copied from Internet protocol stack due to the particular features of MANET [6].

QoS support in MAC layer is a crucial and challenging topic in the research of wireless ad hoc networks [7-8]. MAC protocol has the inherent advantage for QoS. The wireless network requires strict synchronization and is complex in the case of multi-hop mobile allocation and scheduling between nodes. If the network has a larger number of nodes, the complexity will increase sharply, which limits the application of mobility protocols in wireless ad hoc networks. Xiao, Y. et al. presented a two-level protection and guarantee mechanism for voice and video traffic in the EDCA-based distributed wireless LANs, which can support multimedia applications such as voice and video over the wireless medium, a contention based channel access function [9].Chen, X. et al. carried out a research on the enhancements for 802.11 media access control (MAC), in order to get safety applications for vehicular ad hoc network (VANET) or inter-vehicle communication (IVC) [10].To assure QoS support, a new secure routing protocol, named trustworthiness-based quality of service (TQOS) routing, was presented for secure route discovery, secure route setup, and trustworthiness-based QoS routing metrics [11].From the point of view of protocols for wireless networks, Nahrstedt, explored the QoS problem in two aspects: (1) an optimization problem from the interference, mobility, and wireless resource constraints and (2) an algorithmic problem with fundamental algorithmic functions within wireless resource management and protocols, and gave the suggestion to them [12].Nafaa, A. and A. Ksentini proposed a new cross-layer MAC design featuring a delay-sensitive back-off range adaptation along with a distributed flow admission control [13].Wang, L. C. et al. proposed four enhanced mechanisms for the carrier sense multiple access with collision avoidance (CSMA/CA) MAC, which allows an ad hoc network to coexist with the legacy TDMA system [14].Ahn, G. S. et al. proposed a stateless network model, called SWAN, which uses distributed control algorithms to deliver service differentiation in mobile wireless ad hoc networks [15].The above contributions have made a great progress on MANET, but they still have some shortcomings such as: no theoretical analysis model to reveal the relationship between the number of configurable protocol parameters and the degree of service differentiation, not suitable for large-scale network etc.

In order to achieve high QoS support in the MAC layer, this paper presents a novel adaptive QoS model in MANET, by means of the existing QoS models in internet and MANET. By analyzing the problems in SWAN model, the differentiated services algorithm in the MAC layer is proposed instead of the signaling model of best-effort service rate control. Mathematical analysis of this model was verified by calculating its ability to provide QoS guarantees for real-time business. Finally, the model simulation results prove the validity of the proposed theoretical analysis and design.

2 Differentiated Services in the MAC Layer

In SWAN model, there are two aspects in QoS support: one is the admission control algorithms for real-time UDP traffic, and the other is the best-effort TCP control algorithm. For the latter algorithm, the control rate is calculated and determined by the MAC layer feedback. The AIMD algorithm in SWAN model is an efficient algorithm in the application layer control algorithm of the data transmission rate. The rate control module is located in the IP layer and the MAC layer. The AIMD algorithm returns delay data in the MAC layer, and determines the data transmission rate of the next step of the best-effort service. This rate adjustment is not immediate, and it's with delay time for reaching the threshold forcibly by reducing the transmission rate of the best-effort service. If the selected proportion is inappropriate, it may cause the real-time service quality of service cannot be guaranteed because the delay has not been effectively reduced. This will result in lower throughput of business, and the larger idle waste of the channel resources. The same problem may also occur on the rate of increasing the delay when not reaching the threshold selecting in business transmission rate. Each node in the network situation is not the same for different network conditions. To choose a proper parameter for multiplicative decrease and additive increase is a very difficult problem. At the same time, the forcible inserted between the IP layer and the MAC layer results in a complex structure of the system. The practical situation needs major modifications to the existing node structure.

The main purpose is to distinguish services instead of providing the rate control by using a MAC layer directly to different priority queues. It eliminates the upper control process of the transmission rate of the best-effort data hysteresis, and can effectively guarantee the quality of service of the high priority queue. There are a large number of low-priority data that need to be sent. If the high priority data appear to congestion, the low priority data will be a certain rate transmission. The transmission rate is computed by a given formula and MAC parameter estimation. This rate can be controlled at a fairly small level, by setting MAC QoS parameters. There is little effect on its high-priority data. In a new high-priority traffic access, it can remove this part of the bandwidth to guarantee the quality of high-priority business services. When the priority data traffic is small, the best-effort data such as the need may be filled out the remaining bandwidth. It's consistent with the principles and best effort data rate control SWAN original agreement. As a result of the mechanism of differentiated services of the MAC layer, the rate control process is almost in real time. It can effectively increase network throughput and shorten response time. It can prevent the low-priority data from affecting the transmission of the high priority data. In this case, the SWAN and AIMD algorithm for best-effort data rate control do not need to continue to use its whole original model. It can skip the original structure of the access control algorithm for real-time business part in order to simplify the upper structure.

In MAC mechanism of differentiated services, QoS model in 802.11e MAC layer rate control function can be used to replace the previous rate of AIMD algorithm control. It retains classifier to mark. The original rate control function and the function of the different business segments is designed. The part of the function of the admission control is a function module of the bandwidth estimation. It's close to relationship in the MAC layer parameters and planning MAC module. Among the practical application and simulation module, it is still available as a separate module to prepare.

The SWAN protocol uses two service quality levels. There is further room for improvement in the flexibility and elasticity of providing QoS. This paper chooses to keep the two levels of service quality, which can effectively control the best-effort data packets and to ensure that the bandwidth of the UDP packet to the transmission of real time data for determining the mechanism of differentiated services of the MAC layer.

3 Adaptive QoS Model in MANET

3.1 Process of Frame Structure of Signaling

SWAN model needs some modifications in order to adapt to the MAC layer differentiated services mechanisms. Because of the abolition of the rate control module, the business through the admission control module is sent to the next layer. In addition to the proposed control mechanism, business measures are taken into an admission control module. Admission control is not in strict accordance with the less than routing bottleneck bandwidth admission control, which can be accepted by the service method. The left part of the space, it meets the impact to address the business short burst over negotiation traffic and terminal moves, in order to ensure to guarantee the bandwidth. An accepted business standard for admissibility of business remaining bandwidth should be at least 30kb, and this bandwidth can access a voice service. Ad hoc network with mobility may cause unpredictability. The retention of such a bandwidth to provide a buffer is necessary. Although this part of the bandwidth utilization cannot be real-time business, the best-effort service should be utilized. The actual idle bandwidth does not reach this value.

802.11e MAC layer protocol mechanism can be well differentiated services with strong ability to control the business of low priority. However, this method has abandoned the original AIMD algorithm rate control and shaping mechanism. If the best-effort service requirements of the application layer initiates too large, there will be a large number of low priority packets at the MAC layer queuing. These low-priority data transmission rate will be low with the heavier routing load. The low-priority queue is lined after entering the packet is discarded in the MAC layer. Application layer mechanisms can guarantee the retransmission of these packets discarded, but it can also result in additional network overhead. Therefore, the need to control the application-layer contracting the queue is full in the MAC layer. Therefore, a feedback mechanism is designed. When low priority data queue is full in the MAC layer, the admission control module will detect this situation. The accepted admission control module can control the real-time data services and is responsible for the control of the business. When the MAC queue is detected, the system immediately stops sending best effort to lower business data. To avoid too frequent start and stop of transmitting data to the lower layer, the MAC layer queue keeps half empty when the admission control module re-starts sending.

Table 1 shows the model of the signaling frame structure, including probe frames, and initial re-negotiation frames. The frame structure is basically the same, and different frames can be distinguished from type domain. The type domain 0 means it replies detection frame to the destination. All copy detection frame is corresponding domain in addition to the type domain. The type domain 1 denotes the frame sender sends detection frame. It records the bottleneck bandwidth of the domain. The type domain 2/3 means this frame respectively for source-based or network-based re-negotiation message frame. The probe frames of bottleneck bandwidth with 16 bits are not used domain for recording.

Table 1. Frame structure of signaling in SWAN

ID 8bits	Type 8bits	Bottle neck bandwidth/unused16bits
Source address 32bits		
Destination address 32bits		

Figure 1 shows the process of probe frame path from source to the intermediate nodes. Different from data frame, the probe frame must be at the intermediate node through the layers below to achieve the SWAN module. The probe frame here is to be processed with the bottleneck bandwidth. Data frame needs to reach the IP layer that can be forwarded to the next hop, and it does not need to be forwarded to a higher level. Under ordinary ad hoc routing mechanism, detecting frames and data frames cannot be forwarded to a higher level. In this case, it is necessary to modify the IP layer mechanism to add a package format typing in the IP domain of the probe frame. IP layer receives a packet marked this format, and parses out the probe frame and forwarded to the SWAN module. Storage by SWAN module can be written, and the next hop bandwidth data are re-sent to the destination node. Since the path from origin to destination node is still part of the entire route, the route establishment process will not be re-initiated. This approach will not make the original establishment of the routing change.

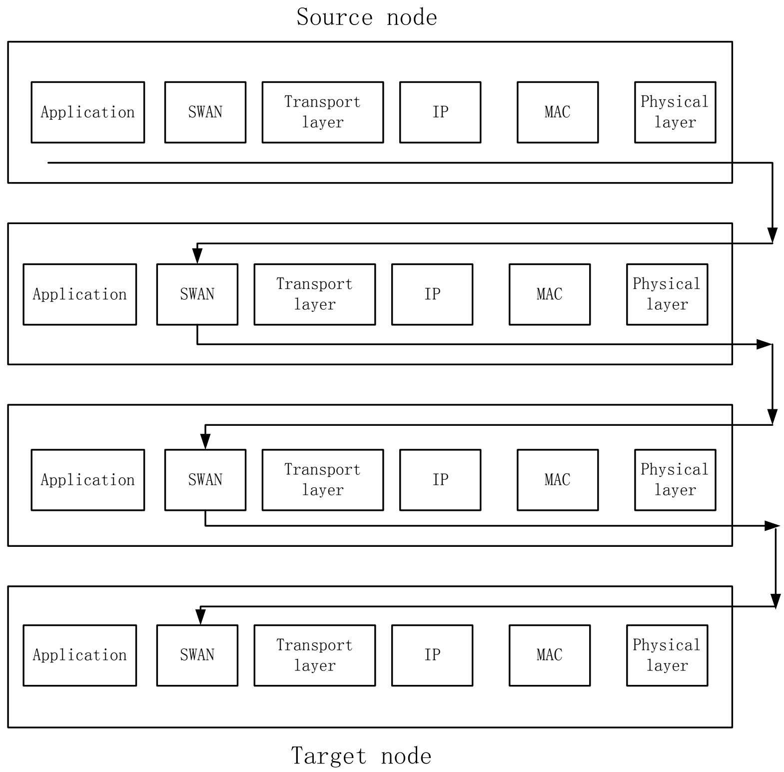

Figure1. Process of original probe frame in all nodes

3.2 Algorithm Analysis

Figure 2 shows the state transition of enhanced distributed coordination function (EDCF) in each slot.

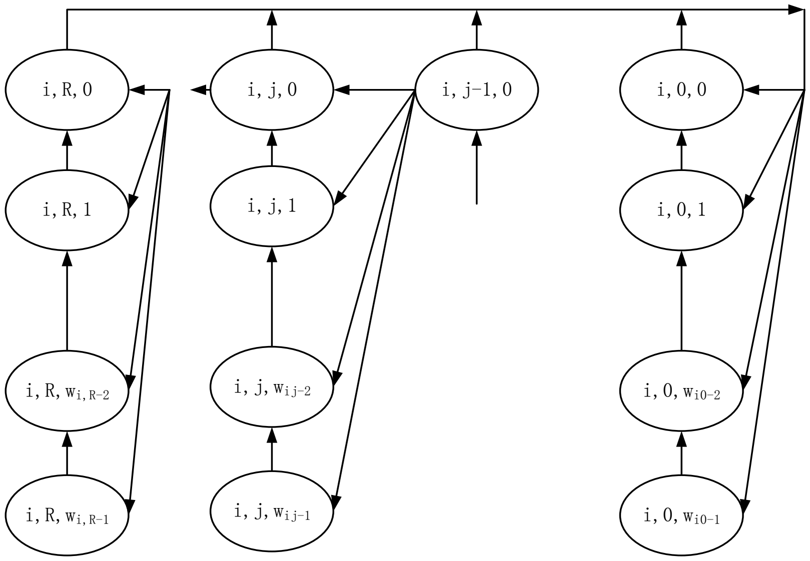

Figure 2. State transition of EDCF

The probability of various transitions has been marked in figure 2. p_i is the probability to find the channel, $w_{i,j}$ is back-off window size, and R is maximum number of retries. $AC(i)$ is the state (i, j, w).

After continuous j collision, the back-off window size is state W . This is a two-dimensional Markov random process. $b_{i,j,k}$ is the random stationary distribution of the process according to the characteristics of the random process.

$$b_{i,j,k} = \frac{W_{i,j} - k}{W_{i,j}} \times \frac{1}{1 - p_{i,k}} b_{i,j,0} \tag{1}$$

Because data transmission happens in the state of 0 in back-off window, namely state $(i, j, 0)$, the probability of sending data for $AC(i)$ is defined as:

$$\tau_i = \sum_{j=0}^{Li,retry} b_{i,j,0} = b_{i,0,0} \frac{1 - p_i^{Li,retry+1}}{1 - p_i} \tag{2}$$

The probability of the busy channel is defined as:

$$p_b = 1 - \prod_{h=0}^{N-1} (1 - \tau_h)^{n_k} \tag{3}$$

The probability of successful transmission data of all nodes within a certain time slot is computed by:

$$p_s = \sum_{i=0}^{N-1} p_{s,i} = \sum_{i=0}^{N-1} \frac{n_i \tau_i}{1 - \tau_i} (1 - p_b) \tag{4}$$

The untransmitted data can be obtained within a certain time slot. The normalized throughput $AC(i)$ is the ratio of the transmission time to the total time, defined as:

$$S_i = \frac{p_{s,i} T_{E(L)}}{(1 - p_b)\delta + p_s T_s + [p_b - p_s] T_c} \tag{5}$$

As the model uses only two priority queues, the ratio of the maximum throughput of the two priority queues is computed by:

$$\frac{S_1}{S_2} = \frac{p_{s,1}}{p_{s,2}} = \frac{n_1 \tau_1 (1 - \tau_2)}{n_2 \tau_2 (1 - \tau_1)} \tag{6}$$

According to the above formula, two priority throughput ratios can be calculated in the same case. $CW_{\min}$ and $CW_{\max}$ is calculated by the highest priority and the lowest priority for 802.11e protocol default parameters. Then the number of nodes in the two businesses is computed to draw two business ratio of the maximum throughput. In the case of two businesses in the full load, the high-priority services can share at least nearly 90% throughput. If the high-priority business needs a 90% throughput, the low-priority business increases the transmission rate. Its rate is limited at the MAC level occupied only 10% of the throughput. Only to increase the number of nodes for low-priority traffic before a share can grow up greater bandwidth. The probability of collisions is increased with the number of nodes. Back-off window of the low-priority traffic is also dramatically increased. The proportion of the corresponding share of bandwidth is not significantly increased. In this case, as long as the application of appropriate admission control algorithm, high-priority business is reliable for service quality assurance.

4 Simulations and Result Analysis

The simulations are carried out with 500m * 500m rectangular range with node communication distance 150m and sharing the same channel. The maximum allowable gap between the actual rate and shaping rate in SWAN model and AIMD algorithm is 10%. Change the TCP operations and the number of the load status in the network, and the transmission of best-effort service node is 10. Greedy strategy is adapted for TCP traffic and FTP service. Keep sending packages to lower queue, and try to seize all resources.

For QoS model, our main concern is the delay of the real-time traffic throughput and best effort services. Compared SWAN model with the improved model by these two parameters, we can see the improvement and the progress. The best effort service node is set to 10. Figure 3 and figure 4 show the comparison of delay parameter of the real-time services of the two models in the MAC layer.

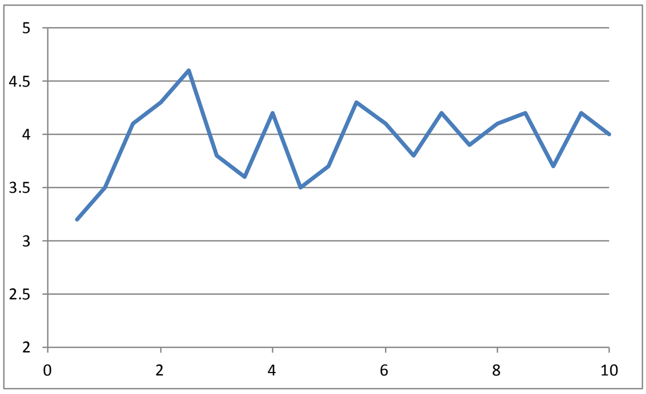

Figure 3. Delay of the improved model

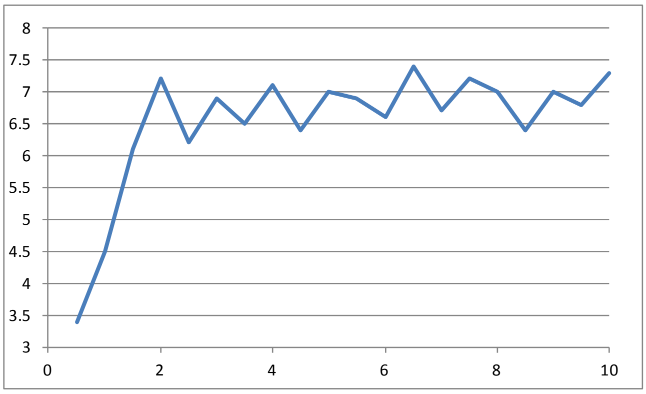

Figure 4. Delay of SWAN model

It can be seen from the figure that the delay of improved model of the real-time service is set to be lower than the SWAN model, and the delay is always stable. The delay of SWAN model is more obvious changing up and down. Only when the delay increases to a threshold to reduce the sending rate of the business, the delay is changing up and down in the proposed model. Among the SWAN model, the delay of real-time service with the best effort service sending rate is increasing. Until the delay exceeds the threshold rate of decline, the delay of real-time business declines. The improved model is more stable.

Figure 5 shows the comparison of the flow of different service nodes when TCP data transmitted successfully.

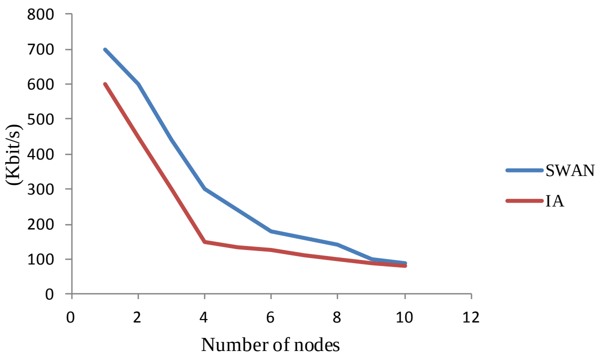

Figure 5. Comparison of the flow of when TCP data transmitted successfully

It can be seen from the figure that the TCP data transmitted successfully in the SWAN model decreases with the increasing number of nodes of the TCP business. Throughput of real-time business maintains a relative value in the proposed model due to the application of the mechanism of the MAC layer differentiated services. TCP business flow is significantly higher than the SWAN model when TCP data transmitted successfully. Differentiated services using a MAC mechanism can not only for real-time services to provide a better quality of service, and it can also provide greater success sending opportunity for best effort data traffic, and the effective use of the bandwidth resources.

It can be seen from the results that the delay of the low-priority traffic is increased by the improved model in the MAC layer. The reason is that the improved model is not in the upper layer of the TCP packet to perform rate control. More packets of data are sent directly into the queue of the MAC layer. These packets in the MAC layer are waiting longer transmission, which causes such delay phenomenon in the MAC layer. This phenomenon is actually the upper delay transferred to the MAC layer, and does not have an adverse effect on the TCP data throughput. Compared with the SWAN model, the proposed approach provides reliable service quality and greater network throughput for MAC Differentiated Services in real-time business. MAC layer mechanism of differentiated services reduces the delay and increases the throughput of the best effort services for real-time business. The improved model performance has been further improved than the original SWAN model.

5 Conclusions

Wireless ad hoc network can quickly build up a mobile communication network compared to conventional communication networks. The biggest difference with other networks is that MANET can be constructed at any time, any place to support the network without hardware network facilities. Its establishment does not depend on the existing network communication facilities, with a certain degree of independence. To provide quality of service guarantee in the network is an important aspect for a network, which is also a research hotspot issue and difficult problem. The main aspect of the research about this problem is to provide different levels of service for different business. For different business, it should provide a different bandwidth, delay, reliability of the service to ensure the various types of services to obtain the required quality of service. To provide quality of service guarantees needs to understand the status and parameters of the network, control access and the rate of new business. This relates to the design of the various layers of the network nodes and cross-layer. It is a system design work, and its research needs in-depth understanding of the architecture of the network and node. Because of the special nature of the wireless ad hoc network, it commonly uses the computer network to provide service quality assurance and the model does not apply to this network. Therefore, it needs a specialized network design model to accomplish this task.

In this paper, a novel adaptive QoS model was presented in MANET. It was improved by differentiated services in MAC layer compared with traditional SWAN model, in order to achieve high control rate of low-priority transactions. The simulations of the proposed model were performed and the results showed that it's feasible and effective in MANET so as to improve the bandwidth utilization and increase the network throughput.

Due to the scarcity of the wireless ad hoc network resources, we have to provide multiple levels of service for further discussion, including the level of quality of services, in order to determine the appropriate number. Moreover, higher requirements for admission control signaling system are increasing. MAC layer differentiated services to provide a quality of service guarantee in the intermediate nodes requires further analysis and verification. Changing signaling system on this basis also needs further design and to be perfect.

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