

An Agent-Based Metric for Quality of Services over Wireless Networks

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Abstract—In a wireless LAN environment, wireless stations with the strongest received signal can not be guaranteed to have the best quality of service if the population sharing the network capacity was not considered. In other words, within the same access point, the more the population, the less the shared bandwidth, and the worse the quality of service will be. In this paper, we proposed an Anticipative Agent Assistance which is an agent-based metric for evaluating and managing the resource of the wireless access points, computing the potential AP list, and providing clients with resource information of APs. We also propose a novel QoS feedback mechanism which allows users to promptly adjust the service quality with AAA according to the throughput and delay requirements. We evaluate the performance of our proposed method using the ns-2 simulator. Numerical results show that AAA help reduce the transmission delay, increase the throughput, improve the network utilization, accommodate more users, and provide load-balancing.

1. INTRODUCTION

IEEE 802.11 [1] has become a popular solution for providing network services in campuses, corporate complex, and public places. Some key concerns to deploy cost effective wireless LANs are regarding capacity planning, load balancing, and resource utilization to provide satisfactory quality of services (QoS) to users.

According to the studies in [2][3][4], the user population is often distributed unevenly among wireless access points (APs). Users tend to be situated in particular areas due to reasons such as network accessibility, locations of power outlets, and personal fondness. This generally results in heavy traffic aggregated in certain areas, and deteriorating the QoS. To address this problem, we proposed so-called anticipative agent assistance (AAA) to improve QoS over wireless LANs. In addition to AAA, we also proposed a novel QoS feedback mechanism, which allows users to dynamically adjust the service quality with AAA according to the throughput and delay requirements. We evaluate AAA system using the ns-2 simulator, and numerical results show that our approach performs remarkably under various user configurations.

The rest of this paper is organized as follows. Section 2 introduces the related works. The design of AAA system is discussed in Section 3. In Section 4 we evaluate the performance of our approach via simulation. We conclude the paper and address the future work in Section 5.

2. RELATED WORKS

In this section we describe existed works which improve the QoS in IEEE WLAN, including the media access control (MAC) layer enhancement, network layer support, system approaches, and hardware solutions.

2.1 MAC-layer QoS Support

The original 802.11 MAC protocol [5] defined two access methods, the Distributed Coordination Function (DCF) which is the fundamental access mechanism used to support asynchronous data transfer on a best effort basis; and the Point Coordination Function (PCF) which is contention-free and aims to support real-time traffic flows [6]. The DCF supports best-effort service, but does not guarantee bandwidth, packet delay and jitter. The PCF is optional for supporting time-bounded services, it still has some constraints: (1) inefficient and complex central polling scheme, (2) unpredictable beacon delay, (3) un-deterministic transmission time of the polled stations. Problems come with the coexistence of DCF and PCF are addressed in [7][8][9]. To support QoS, IEEE 802.11e [10] defines enhancements to 802.11 MAC. Besides, there has been a number of proposals for MAC protocol in WLAN to support differentiated services [11][12][13][14][15]. However, all of these methods focus on scheduling and fairness for individual MAC without considering the dynamic nature of wireless network services.

2.2 Network-layer QoS Support

In [16], the authors present a cluster-based approach to inform the source regarding the bandwidth and QoS available to a destination. This enables the establishment of QoS connections within the wireless network and the efficient support of real-time traffic. In [17], author proposed a distributed QoS routing scheme which selects a route with sufficient resources to satisfy certain delay and bandwidth requirement in a dynamic multi-hop mobile environment. These algorithms work with imprecise state information to select the best qualified path. In [18], a predictive location-based QoS routing scheme is proposed based on a low-cost location-resource update protocol to assist predicting future routes before existing routes break so as to avoid route re-computation delay.

In [19], a new distributed routing algorithm is proposed performs the dynamic load-balancing for wireless access

networks. It introduced the idea of load-balanced backbone tree, which simplifies routing and avoids per-destination state for routing as well as per-flow state for QoS reservations.

2.3 Hardware-based QoS Support

Vendors like Cisco [20] and OriNOCO [21][22] have their wireless client adapters equipped with site-survey tools to detect the signals from the neighbor access points. With this tool users can learn statistical information regarding the access points, including nearby access points, signal strength and quality, receive and transmit statistics, and link status. To some extent these information may be helpful for users while selecting access points. Mobile users will most likely choose the AP with stronger signal for better link quality. However, this does not guarantee better QoS as there might be more users accessing the selected AP. Moreover, it is a burdensome work for wireless users to keep tracking the status of each AP.

2.4 System-based QoS Support

Microsoft Corp. has incorporated a so-called Microsoft Wireless Configuration Manager in its Windows 2000/XP. It helps users configure the settings of wireless network such as switching between infrastructure and ad hoc modes, security option, and IEEE 802.1x authentication.

DIRAC in [23] is a software-based router system designed for wireless networks to support three functions: link-layer assisted fast handoff, channel-adaptive scheduling, and link-layer enforced policing. However, it is unable to inform the mobile users ahead of moving to the access point with more available resources. Hence, we take this feature into account in our system design, and define the action to inform the mobile users beforehand as anticipative assistance.

3. PROPOSED APPROACHES

3.1 Motivation

A user may find a situation that the service quality is still poor even the 'qualified' AP is chosen. The following two scenarios are demonstrated as examples.

Figure 1 shows four access points installed in a conference room. While you enter the room, the wireless utilities will soon indicate that the AP-1 is your best choice since it features strongest signal near the door. Nevertheless, it is very likely that service provided by AP-1 is worse than that provided by AP-4 because AP-1 is serving more users.

In another scenario, you are located around Gate 4 in a busy international airport waiting for the flight. The departure time is 15 minutes later and it has started on board. Gate 4 is crowded and many passengers get on Internet through the wireless LANs. Suddenly, your boss phones you and asks you to email an important document to him immediately. You promptly attempt to send the email, but you may find that transmission speed is too slow to make it through before taking off. Meanwhile, Gate 7, another gate three corners away has only few wireless users. Unfortunately, you were not aware of the situation. Hence, the key missing piece is a system framework that is able to inform you the overall status of the network, and provides assistance beforehand.

Based on the above ideas, we propose a novel approach called anticipative agent assistance (AAA), which is a centralized framework providing various forms of interaction between users and agents in order to improve the QoS over wireless networks.

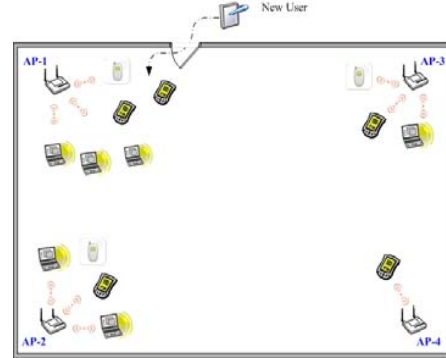


Fig. 1. WLANs in a conference room.

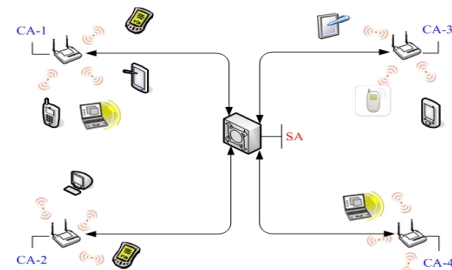


Fig. 2. AAA architecture.

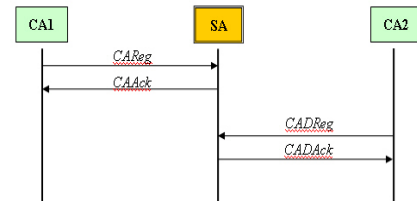


Fig. 3. SA-CA interaction.

TABLE I CA-RECORD MAINTAINED IN SA

ID	IP	Loc_X	Loc_Y	Loc_Z	MN	Bw
CA1	1,0,0,0	50,0	50,0	0,0	5	11Mb
CA2	2,0,0,0	550,0	50,0	0,0	3	54Mb
CA3	3,0,0,0	550,0	550,0	0,0	8	11Mb
CA4	4,0,0,0	50,0	550,0	0,0	1	54Mb

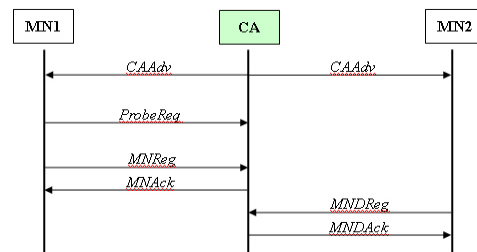


Fig. 4. CA-MN interaction.

3.2 Anticipative Agent Assistance

A. Design Rationale of AAA

As shown in Fig. 2, AAA uses a centralized architecture composed of a sever agent (SA) and numerous client agents (CAs) which are installed at access points. The connection between a SA and a CA is wired. Each CA can arbitrarily join or leave an AAA group. For example, when a mobile user enters a wireless domain under CA-1 and requests AAA support, CA-1 will send an assistance request message to SA. SA calculates the qualified CA list and sends this information to the user through CA-1. With AAA enabled, each mobile user will soon be advised whether to move or not before starting to work on line. The number of CAs supported is not restricted. AAA adopts the centralized design due to following concerns: (1) Easily control and monitor the network status, (2) Lighten the load of CAs, and (3) Reduce the overhead of intercommunications between CAs. Three forms of AAA interactions are discussed in the following.

B. SA-CA Interaction

In Fig. 3, registration and deregistration procedures are defined in the SA-CA interaction. The former is initialized by a new CA when it wants to join an AAA group. The CA starts the registration process by sending a *CAReg* message to SA. The *CAReg* message contains the essential information such as CA's ID, CA's IP address, X/Y/Z coordinates, number of mobile users, and available bandwidth. Once the registration requested by a CA is approved, a *CAAck* message initialized by SA will be sent back to the CA to finish the registration procedure. Otherwise, a *CAFail* message with failure code will be sent back to CA. Regarding the latter, a CA can quit the AAA group by sending a *CADReg* message to SA for reminding SA to remove its record from CA-record (Table 1).

SA maintains a CA-record in its database as reference and the input for future assistance queries. SA also takes charge of the mutual communications among CAs. Thus, CA is exempted from maintaining an individual database and frequent communication with other CAs.

Figure 4 shows three kinds of procedures in the interaction between CA and Mobile Node (MN). The first one is advertisement procedure. A CA at the access point periodically broadcasts advertisement messages. For the overall network performance concern the frequency of advertisement broadcasting can be set to once per minute. The *CAAdv* message is composed of CA's ID, CA's IP address, elapsed time, and AAA enforcement option (default OFF). Elapsed time field in *CAAdv* message defines the valid lifetime of an advertisement, and AAA enforcement option (ON/OFF) is to determine whether to ask all mobile users to enable AAA support for the purpose of load-balance.

C. CA-MN Interaction

Upon receiving the advertisements from CA, MN will soon check its AAA setting. If it is ON, MN will send a *ProbeReq* message to CA for requesting AAA services; otherwise MN acts as a normal node. After that, MN may move to another CA domain. Then MN has to initiate a registration process

which sends a *MNReg* message to the corresponding CA, with the content including MN's ID, MN's IP address, AAA support, and QoS option. The value of AAA support is based on users' AAA setting, and QoS option will be introduced in the following. While CA accepts registration request from a MN, it will update its information in SA's CA-record and a registration acknowledgement will be sent back to the MN.

If a MN intends to leave for another location, it starts a deregistration process and sends a *MNDReg* message to the associated CA, then waits for the reply to terminate the procedure.

D. SA-CA-MN Interaction

Since MN has two settings, AAA support and QoS option, the combination of these two values will result in three different types of interaction, [AAA OFF/QoS OFF], [AAA ON/QoS OFF], and [AAA ON/QoS ON].

Case 1: AAA OFF/QoS OFF

When a MN enters the coverage of CA-1, it soon hears the advertisement and then sends a *MNReg* message to CA-1. After checking the value of AAA field, CA-1 generates a *CF+MNReg* message to SA for updating the field and number of mobile users in CA-record. Once the update has been done, a *CF+MNack* message is created by SA to inform CA-1 of successful modification. Finally, CA-1 sends a *MNack* message to terminate the registration procedure. The detailed message flow is elaborated in Fig. 5.

Case 2: AAA ON/QoS OFF

When a MN gets into the coverage of CA-1, it soon senses the advertisement and checks its AAA setting. Since the AAA is ON, the MN sends a *ProbeReq* message to CA-1 right away. The *ProbeReq* message contains MN's ID, MN's IP address, X/Y/Z coordinates, and distance-sensitive option, which is used in the *CalBest* algorithm described below and is configured by a MN. CA-1 checks the type of received message and attaches its IP address to the end of message to form a new message, *CF+PbReq*, which is forwarded to SA. SA recognizes the *CF+PbReq* message as an AAA query and uses the *CalBest* algorithm to output the recommended movement in the *CF+BstAck* message.

The *CalBest* algorithm takes four parameters as its input, X/Y/Z coordinates, and distance-sensitive option in the *ProbeReq* message. If the distance-sensitive option is OFF, which means to select a least-load AP without considering the distance between the mobile user and the new AP, *CalBest* sorts the CA-record based on the number of mobile users and available bandwidth. In TABLE I, CA-4 will be recommended to the MN. On the other hand, if the distance-sensitive option is ON, *CalBest* algorithm first repeats the sort procedure, and those qualified finalists with load slighter than current AP are sorted again based on the distance to the mobile user. In TABLE I, CA-2 replaces CA-4 as the best choice.

Following the output of *CalBest*, SA generates a *CF+BstAck* message to CA-1, which then informs MN of recommended movement by sending a *BstAck* message. MN moves to the suggested location and initiates the regular

registration procedure. Figure 6 illustrates the message flow among SA, CA, and MN.

Case 3: AAA ON/QoS ON

The purpose of QoS option is to periodically check the throughput, delay or jitter of a connection. Once these performance values degrade to below a threshold for certain time period, a *ProbeReq* messages will be automatically sent to the corresponding CA on behalf of the MN.

In case 2, if a MN has moved from a heavy traffic area (CA-1) to a suggested light traffic area (CA-4), it gets the guaranteed QoS at the beginning. As time passed by, more users with AAA off enter into the coverage of CA-4. If the MN was not aware of other users' joining the same BSS, the throughput of the connection may drop drastically. With QoS option, a monitor mechanism in MN will keep tracking the throughput. If it was under the threshold for a certain time period, the monitor mechanism sends a *ProbeReq* message to CA-4 for another AAA query. Consequently, the MN will soon be advised to move to another area for QoS sake, thus it will ensure the QoS for the entire connection period.

TABLE II shows the thresholds for various service classes. Moreover, Figure 7 demonstrates the message flow in case 3, in which a *ProbeReq* message has been automatically created and sent to CA-4. Meanwhile, MN waits for the *BstAck* message from SA. Once the *BstAck* message is received by a MN, the MN deregisters with CA-4 before moving to the recommended area, CA-2. When the deregistration procedure is done, MN will immigrate to CA-2 and then initiates the regular registration process.

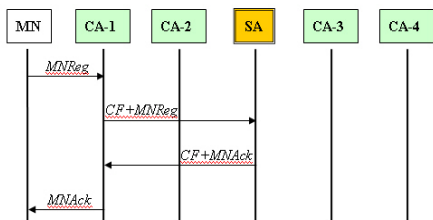


Fig. 5. Message flow in case 1.

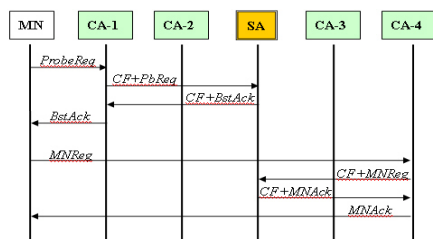


Fig. 6. Message flow in case 2.

TABLE II THRESHOLD FOR SERVICE CLASSES

Code	Class of Service	Throughput	Delay	Jitter
0	Default	T_D	D_D	J_D
1	Best effort	T_BE	D_BE	J_BE
2	Voice	T_VO	D_VO	J_VO
3	Video	T_VI	D_VI	J_VI
4	Reserved	-	-	-

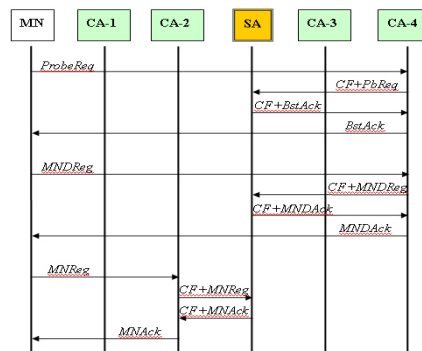


Fig. 7. Message flow in case 3.

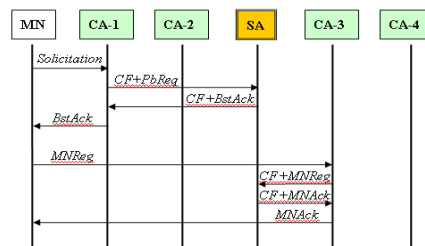


Figure 8: Solicitation message flow.

E. Solicitation

In the original design, AAA service is requested through sending out a *ProbeReq* message by MNs. However, a *ProbeReq* message only can be generated when the value of AAA support or QoS option is on. In Fig. 8, a solicitation function is introduced, so that a MN is allowed to manually send a *Solicitation* message to request AAA service anytime.

When a MN acquires the QoS, it sends a *Solicitation* message to request AAA service rather than waits for later reaction initiated by QoS option. In Fig. 7, a MN sends a *Solicitation* message to the currently associated CA-1 and waits for the advices from SA. Meanwhile, MN deregisters with CA-1 so as to migrate to other location. Afterward MN moves to CA-3 and begins the regular registration procedure. Thus, the solicitation function gives MNs the flexibility either automatically or manually by our AAA system.

3.3 Design Goals

Through the interactions with agents, MNs are expected to acquire anticipative assistance. Our design goals are: (1) to reduce the transmission delay, (2) to increase the throughput, (3) to improve the overall network utilization, (4) to accommodate more users to access the network, and (5) to provide load-balancing mechanism.

Goals (1) and (2) can be achieved by the joint use of AAA support and QoS option, and Goal (3), (4), and (5) can be achieved via the AAA enforcement option in the *CAAdv* advertisement message broadcasted by the CA. Once the AAA enforcement option is turned on, the system will notify all users to be evenly distributed to different areas for the load-balancing consideration. This will prevent users from crowding in some specific areas so as to improve the overall network utilization.

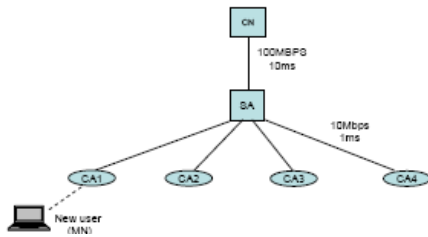


Fig. 9. Simulation scenario I.

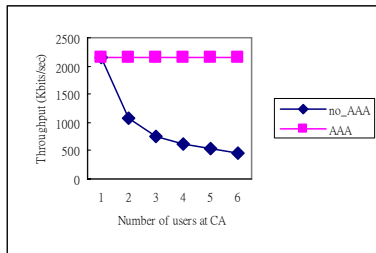


Fig. 10. MN's throughput.

4. PERFORMANCE EVALUATION

4.1 Individual User AAA-support Enabled

A. Simulation Scenario I

Figure 9 illustrates the network topology in our first test set. Four CAs separately connect to the SA with a 10 Mbps/1 ms wired link, and it is a 100Mbps/10ms link between CN and SA. 802.11b is used to facilitate the communication for mobile users and CAs. The mobile users start the FTP application destined to the CN with TCP traffic, and here we simulate that a new MN is entering CA-1 area. The simulation time is 300 seconds. We use various initial user distributions for CA-1 to observe how a new MN benefits from our AAA support. The user distributions for CA-2, CA-3, and CA-4 are 3, 2, and 0 respectively.

B. Result and Analysis I

Figure 10 shows the MN's throughput under various user distributions at CA-1. When a MN is entering the coverage of CA-1 where one user is already there, the MN's throughput is about 1079 Kbps. However, the throughput is decreased to 458 Kbps while the number of users reaches 6. We are sure that the throughput is definitely going down if more users join CA-1 and the MN is not aware of the user population. On the other hand, with AAA support, the throughput of MN is maintained at 2158 Kbps no matter how many users are associated with CA-1. This is because MN enables the AAA-support so that it is directed by AAA system to move from CA-1 to CA-4, where no other user competes for the resources, thus the MN will surely be better served.

The sending rate and RTT are illustrated in Figure 11 and 12 respectively. With the AAA enabled, MN's average RTT is 7.36 ms. From Fig. 11, we can easily recognize that the sending rate with six users is not as stable as that with AAA support. The same situation happens to RTT as well. The RTT with six users ranges between 25 ms and 80 ms, but only between 5 ms and 9 ms with AAA support. In addition, we

also attempt to add more users to CA-1. However, the RTT dramatically increases to hundreds milliseconds and the sending rate becomes very unstable. The reason is that the queue of AP overflows thus seriously deteriorates the QoS for mobile users. Hence, the probability of aggravating QoS will be substantially decreased by using the AAA. The user distribution at each CA is summarized in Fig. 13. With AAA support, the number of users at CA-1 decreases from 6 to 5, and increases from 0 to 1 at CA-4.

C. Simulation Scenario II

Configuration of scenario II is similar Fig. 9 except that link speeds of SA-CN and SA-CA change to 10Mbps/10ms and 1Mbps/1ms, respectively. It differs from scenario I in the direction of data transfer, link capacity, and application. Here CN sends the audio flows to the mobile users through CA. The audio flow is 64 Kbps UDP traffic with packet size 210 bytes. The link capacities for CN-SA and SA-CA have been changed to 10 Mbps/10 ms, 1Mbps/1 ms, respectively. The simulation time is still 300 seconds.

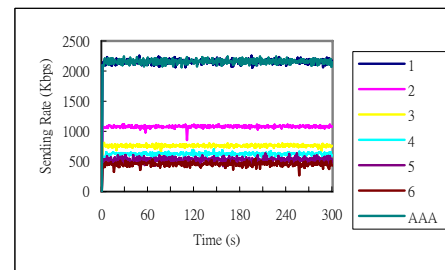


Figure 11: MN's sending rate.

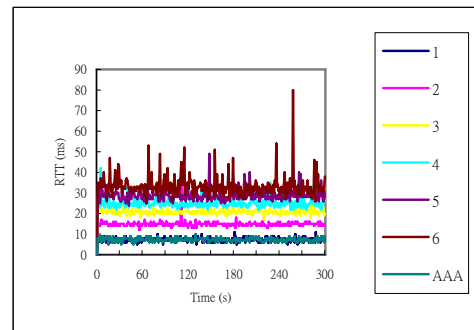


Figure 12: Round trip time for MN's FTP application.

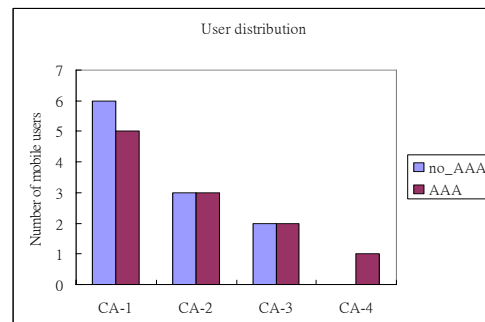


Figure 13: User distribution at each CA.

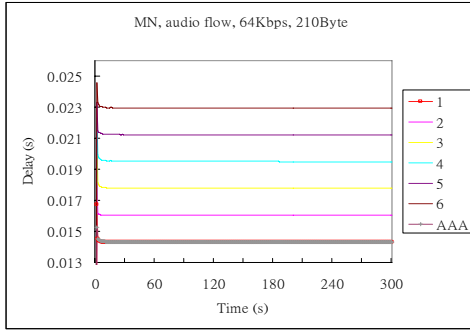


Fig. 14. End-to-end delay for audio traffic.

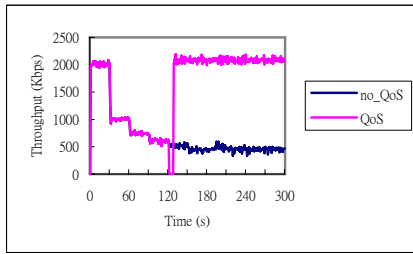


Fig. 15. MN's sending rate.

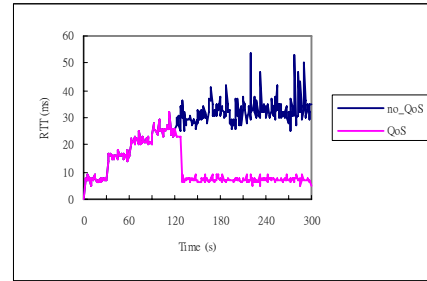


Fig. 16. Round trip time for MN's FTP application.

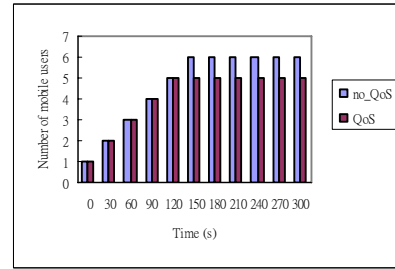


Fig. 17. User distribution at CA-1.

D. Result and Analysis II

Figure 14 shows the delay for audio flow received at a MN. We could find that the delay is proportional to the number of mobile users. The delay varies from 0.014 second to 0.023 second. If the AAA-support is enabled, the delay can be reduced to as low as 0.014 second. We also attempt to increase the number of user to more than 6. Not surprisingly, the end-to-end delay greatly increases to hundreds of milliseconds (647 ms or higher) and the sending rate becomes very unsteady. The reason is that the queue of AP overflows.

4.2 Individual User AAA-support and QoS-option Enabled

A. Simulation Scenario III

We use the same configuration as in Fig. 9 in scenario III. The initial user distributions are 0, 3, 2, and 0 for CA-1 to CA-4 respectively. Since the MN enables both AAA-support and QoS-option, it is directed to CA-1 as recommended by AAA at the beginning. In order to verify the benefit of QoS-option, we add one mobile user every 30 seconds at CA-1 until the number of users raises to 6. The QoS threshold is set as 1000 Kbps. Other settings such as link capacity, application, and transfer direction, are same as that in scenario I. Furthermore, for service continuity, every mobile user has mobile IP [25] enabled while migrating to other CAs.

B. Result and Analysis III

Figure 15 and Fig. 16 illustrate the sending rate and RTT for MN's FTP application. In Fig. 15, the MN's throughput decreases from 2064 Kbps to 1008 Kbps when adding a user to CA-1 at 30th second. At 60th second, another user gets into the CA-1 area (3 users in total), the throughput drops to 712 Kbps. At the same time, the monitor mechanism launched by QoS-option keeps tracing the throughput based on the specified threshold for the following 60 seconds.

At 120th second, the total number of mobile users reaches 5 and MN's throughput keeps decreasing. Thus the monitor mechanism generates a *ProbeReq* message to request AAA's support. MN takes the suggestion so as to move from CA-1 to CA-4 at 122nd second. During the handoff (122nd sec – 131st sec), MN starts the Mobile IP to ensure the service continuity. At 131st second, MN arrives at CA-4 and the throughput goes up to 2168 Kbps again. Meanwhile, RTT rapidly decreases from 32 ms to 6 ms. On the contrary, without the QoS-option, MN's throughput drops drastically to as low as 336 Kbps and RTT raises to as high as 54 ms. Figure 17 summarizes the user distribution at CA-1 for the entire trace. MN's migration (at 122nd second) and new user's participation (at 150th second) results no change in the number of users.

4.3 AAA-enforcement-option Enabled

A. Simulation Scenario IV

Configuration of scenario IV is similar to Fig. 9 except that link speeds of SA-CN and SA-CA change to 10Mbps/1ms and 2Mbps/2ms. Here AAA-enforcement option is enabled and MNs are sending TCP traffic to CN. The mobile users are unevenly distributed at each CA, and we assume that the user distribution is 5, 3, 0, and 0 for CA-1 to CA-4 respectively without AAA enforcement. The default queue size is 50, and the simulation time is 300 seconds.

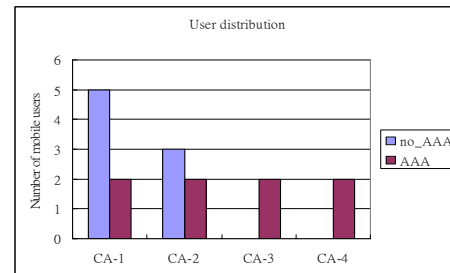


Fig. 18. User distribution at each CA.

B. Result and Analysis IV

Since the AAA enforcement is enabled, every mobile user will be asked to move to the assigned CA while entering the wireless area. In Fig. 18 we can see that all the users are equally dispatched to four CAs, this function indeed achieves the load-balancing and reduces the probability of congestion in certain areas. Here we define the link between SA and each CA-1 through CA-4 as Link1 to Link4, respectively. Figures 19 and Fig. 20 show the queue occupancy of each link.

The default queue size of each link is 50 packets. Without the AAA enforcement, the queue occupancy of Link1 can be very fluctuant and ranges between 0 and 49 (Fig. 19). Once the queue space runs out, it results in packet drop. From Fig. 21 we observe that the packet drop for Link1 can be as high as 960 packets. Link2 experiences the same problem at the same time. The range for queue size of Link2 is between 13 and 49, and also leads to 261 packet drops. Since all users congregate in CA-1 and CA-2, the queue sizes for Link3 and Link4 are always zero, and there is no packet drop. On the other hand, if the AAA enforcement is enabled in the beginning, the packet drop for each link eventually reduces to zero and the queue size of each link keeps steady without overflowing during the entire trace. Figures 19~20 illustrate that the queue size for each link ranges between 35 and 37. This feature not only increases the possibility of providing QoS, but also improves the network utilization through load-balancing. In addition, it may accommodate more users to access the wireless network. Generally speaking, a link with minimum packet drop is critical to time-sensitive services, such as VoIP, video, streaming media, and interactive gaming. With AAA enforcement, chances are much higher to keep the users staying in the network and to allow more users joining to the same group simultaneously.

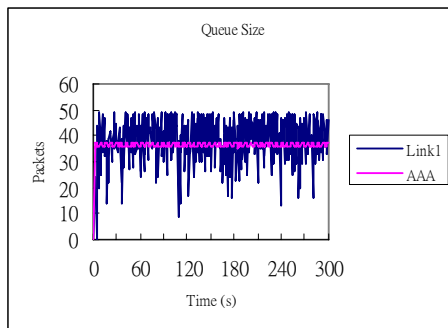


Fig. 19. Queue occupancy for SA-CA1 (SA-CA2) link.

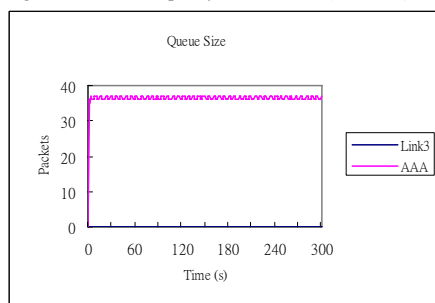


Fig. 20. Queue occupancy for SA-CA3 (SA-CA4) link.

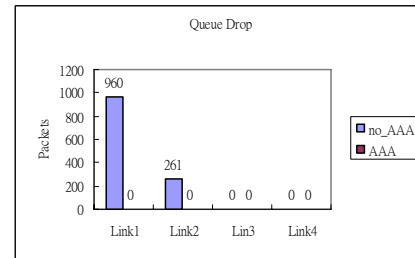


Fig. 21. Queue drop for each link.

C. Simulation scenario V

The scenario V configuration is same as that in Scenario II, but here CN acts as a streaming media server and transmits video to mobile users. The sending rate is 384 Kbps VBR and packet size is 800 Byte in UDP. Here MN is the first one who enters the CA-1 area. After that, CA-1 takes in one more user every 30 seconds until the total number of users increases up to 8. Following the assumption in scenario IV, we assume that the user distribution will eventually be 8, 0, 0, and 0 for CA-1 to CA-4 without AAA enforcement.

D. Result and Analysis V

In Fig. 22, the delay for MN's video flow is kept at 19 ms before 60th second. At 61st second, the delay begins to increase and the total number of users at CA-1 has reached 3. Between 61st second and 160th second, three additional users joined CA-1 (6 users in total), the delay increases steadily but slowly and the loss rate maintains at zero as shown in Fig. 23. After 160th second, however, both the delay and loss rate suddenly raise and keep going up for the rest of the trace. The 8th user gets into CA-1 area at 210th second, and the delay is as high as 120 ms and loss rate reaches to about 8%. Even there is no other users joining CA-1 area after 210th second, the delay and loss rate still keeps aggravating in the later half of the trace (210th – 300th second). At the end of trace, the delay is raised up to 156 ms and the loss rate climbs up to 22%. On the contrary, if AAA enforcement is enabled, MN and other users will be evenly directed to four CAs as shown in Fig. 24. Moreover, the MN maintains the delay at 19 ms for the entire trace, and the loss rate is also reduced to 0% till the end. From the aforementioned discussion, we conclude that with the introduction of AAA enforcement messages, both MN and other mobile users are guaranteed to receive a service with acceptable QoS, and meanwhile the goal of load-balancing can be achieved.

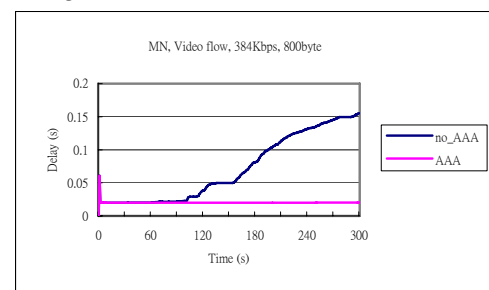


Fig. 22. Delay for MN's video flow.

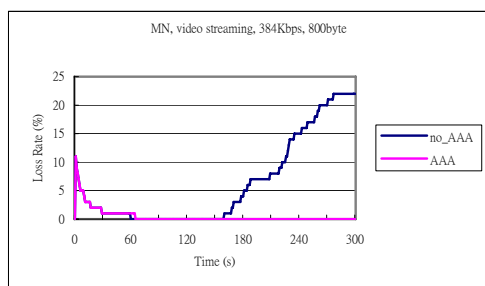


Fig. 23. Loss rate for MN's video streaming flow.

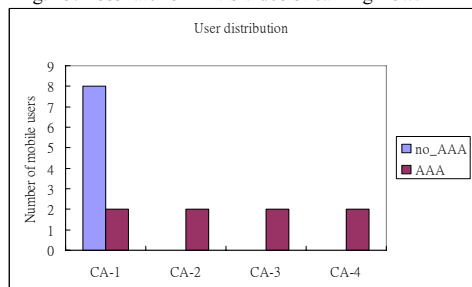


Fig. 24. User distribution at each CA.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed an agent-based system for improving quality of service over wireless LANs. The proposed method, AAA system, is basically a metric mainly responsible for managing the control information of the entire wireless access points, generating the potential AP list with our *CalBest* algorithm, and informing the users of AP (or CA) with least load. Through the interaction with agents, mobile users are expected to acquire anticipative assistance from our AAA system. Furthermore, we introduce a novel idea, the QoS option, which allows users to promptly adjust the service quality with AAA system according to specified threshold of throughput, delay or jitter. For the load-balancing purpose, we incorporate the AAA enforcement option in the advertisement messages. With the AAA enforcement enabled, all mobile users will be directed by AAA system based on the load-balancing mechanism. Also, we extend the AAA system with the solicitation function, which allows users to request AAA service whenever needed.

We use ns-2 to evaluate the performance of AAA system with various scenarios and user configurations. It shows that AAA system (1) reduces the transmission delay, (2) increases the throughput, (3) improves the overall network utilization, (4) accommodates more users in the same network, and (5) provides load-balancing.

We conclude this paper with some possible future work. First, we note that the AAA system is yet to be put into practice. If the system is implemented on the access points/base stations, the network load can be easily controlled and the users will be better served within the wireless network. In addition, AAA system can cooperate with SNMP (Simple Network Management Protocol) to gather more precise information for reference when *CalBest* algorithm makes its

decisions. Moreover, users may send a service agreement which indicates the maximum and minimum bandwidth needed for different classes of service to the SA for accurately reserve the resource. Also, SNMP here can be a great help for providing the necessary information to the reservation. Finally, since the AAA system is in server-client architecture, we expect to eliminate the centralized framework by introducing a routing protocol which is like RIP, OSPF, IGRP or IGRP to enable the communications between CAs. With the support of such protocol, the system can be further simplified.

REFERENCES

- [1] IEEE 802.11b/d3.0 Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, August 1999.
- [2] D. Tang and M. Baker, "Analysis of a Local-Area Wireless Network," *Proceedings of ACM MobiCom '99*, pp. 13-23, August 1999.
- [3] D. Tang and M. Baker, "Analysis of a Local-Area Wireless Network," *Proceedings of ACM MobiCom '00*, pp. 1-10, August 2000.
- [4] D. Kotz and K. Essien, "Analysis of a Campus-wide Wireless Network," *Proceedings of ACM MobiCom '02*, pp. 107-118, September 2002.
- [5] IEEE 802.11 Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, August 1999.
- [6] A. Lindgren, A. Almquist, and O. Schelén, "Quality of service schemes for IEEE 802.11 wireless LANs: an evaluation," *Mobile Networks and Applications, Volume 8 Issue 3*, pp.223-235, June 2003.
- [7] B. P. Crow, I. Widjaja, J. G. Kim, and P. Sakai, "Investigation of the IEEE 802.11 medium access control (mac) sublayer functions," *Proceedings of IEEE Infocom '97*, pp. 126-133, April 1997.
- [8] T. M. Veeraraghavan and N. Cocker, "Support of voice services in IEEE 802.11 wireless LANs," *Proceedings of IEEE Infocom '01*, pp. 488-497, Polytechnic University, April 2001.
- [9] M. Visser and M. ElZarki, "Voice and Data Transmission over an 802.11 Wireless Network," *Proceedings of IEEE PIMRC '95*, pp. 648-652, September 1995.
- [10] S. Mangold, S. Choi, Peter May, Ole Klein, Guido Hiertz, and Lother Stibor, "IEEE 802.11e Wireless LAN for Quality of Service," *Proceedings of European Wireless '02*, pp. 32-39, Italy, February 2002.
- [11] I. Ada and C. Castellucia, "Differentiation Mechanisms for IEEE 802.11," *Proceedings of IEEE Infocom '01*, pp. 209-218, March 2001.
- [12] G. Bianchi, L. Fratta, and M. Oliveri, "Performance Evaluation and Enhancement of the CSMA/CA MAC Protocol for 802.11 Wireless LANs," *Proceedings of IEEE PIMRC '96*, pp. 392-396, 1996.
- [13] M. Barry, A. T. Campbell, and A. Veres, "Distributed Control Algorithms for Service Differentiation in Wireless Packet Networks," *Proceedings of IEEE Infocom '01*, pp. 582-590, April 2001.
- [14] H. Kim, and Jennifer C. Hou, "Improving Protocol Capacity with Model-based Frame Scheduling in IEEE 802.11-operated WLANs," *Proceedings of ACM MobiCom '03*, pp. 190-204, September 2003.
- [15] N. Vaidya, P. Bahl, and S. Gupta, "Distributed Fair Scheduling in a Wireless LAN," *Proceedings of ACM MobiCom '00*, pp. 167-178, Aug. 2000.
- [16] T. Chen, J. Tsai and M. Gerla, "QoS Routing Performance in Multihop, Multimedia, Wireless Networks," *Proc. of IEEE ICUPC*, pp. 557-561, 1997.
- [17] S. Chen, and K. Nahrstedt, "Distributed Quality of Service Routing in Ad hoc Networks," *IEEE JSAC*, pp. 1488-1505, August 1999.
- [18] S. Shah, and K. Nahrstedt, "Predictive Location-based QoS Routing in Mobile Ad hoc Networks," *Proceedings of IEEE ICC '02*, pp. 1022-1027.
- [19] P. Hsiao, A. Hwang, H. T. Kung, and D. Vlah, "Load-Balancing Routing for Wireless Access Networks," *Proc. of IEEE Infocom '01*, pp. 986-995.
- [20] Cisco Aironet 350 Series (Aironet AIR-PCM 352 Wireless Lan Adapter), March 2004.
- [21] Agere Systems Inc. NDIS 5 USB Driver for MS Windows XP, 2002.
- [22] Boingo Software, version 1.1, 2002.
- [23] P. Zerfos et al., "DIRAC: A Software-based Wireless Router System," *Proceedings of ACM MobiCom '03*, pp. 230-244, September 2003.
- [24] The Network Simulator - ns-2, <http://www.isi.edu/nsnam/ns/>.
- [25] C. Perkins, "IP Mobility Support," IETF RFC2002, October 1996.