

3-6 QoS-aware Resource Allocation and Utilization Technology in Access Networks

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Future pervasive ubiquitous networks will be constructed by various access networks such as wireless LAN and cellular networks. Such wireless access networks have a variety of capacity and dynamics compared with core networks, so that they have a significant impact on end-to-end communication in terms of quality of service. Therefore, we focus on the QoS-aware resource allocation and utilization technologies in access networks. In the present paper, we introduce our proposed intra-domain and inter-domain schemes to improve communication quality.

Keywords

Resource allocation and utilization, Wireless access networks, Intra-domain technique, Inter-domain technique, Pervasive ubiquitous networks

1 Introduction

With the rapid development of wireless communication technology, wireless networks featuring diverse speeds and characteristics are becoming widespread; moreover, these networks are beginning to transform into pervasive, ubiquitous network—means of accessing the Internet at any time and in any location. Wireless LANs and cellular networks are already in extensive use; the former support high-speed communications and the latter cover wide areas (though at low communication speeds). Further, more access networks with a diverse range of functions are expected to appear in the future. At the same time, Internet applications are also becoming increasingly diverse. Traffic with various characteristics is transmitted over fast core networks and multiple access networks, accompanied by increasingly complex demands for required quality of service (QoS) in communication. Given this background, we can assume that efficient and equitable realiza-

tion of high-grade end-to-end communication will be extremely important in a future, expanded Internet. Specifically, wireless access networks provide a wide range of quality of service compared with conventional wired access networks or high-speed core networks, with significant potential impact on end-to-end communications. Thus, dynamic, adaptive QoS-aware technologies for resource allocation and utilization will be necessary to satisfy the required QoS demanded by applications in access networks. Users are looking for the resources they need when they need them, while service providers prioritize the efficient and equitable allocation of these resources. The technologies to be established for resource allocation and utilization must satisfy both.

This paper focuses on diverse access networks near the user, including wired and wireless networks; the aim of the discussion is to foster improved QoS in end-to-end communication and to promote the efficient use of limited resources. To accomplish these goals, we

regard the problem from two points of view: in terms of intra-domain QoS-aware technologies for resource allocation and utilization (for a single-domain access network operated by a single management organization), and in terms of inter-domain technologies for resource allocation and utilization (for pervasive ubiquitous networks in which two or more access network domains are simultaneously available. Section 2 of this paper introduces the access point selection method in a wireless LAN access network to illustrate problems related to intra-domain techniques, and Section 3 presents the access network selection method to highlight problems related to inter-domain techniques.

2 Access point (AP) selection method for wireless LAN

This section focuses on Internet/intranet wireless LAN access networks operated by single organizations such as private enterprises or universities, and proposes a method for equitable and efficient use of wireless LAN resources.

2.1 AP selection for wireless LAN

The spread of wireless LANs has increased demand for the use of wireless LANs in more locations. However, the wireless communication resources provided by a single wireless LAN Access Point (AP) are shared by all terminals (or stations, abbreviated as STAs) connected to the AP, so that the throughput per STA decreases with a greater number of connected STAs. Generally, approximately 20 STAs per AP is seen as the limit. The radio waves emitted from the AP are considered to reach 150 m outdoors and 50 m indoors (with relatively few obstacles). To provide communication over longer distances, the communication area must be extended by constructing the wireless LAN of two or more APs. In other words, to meet user demands in this area, two or more APs are required for a given wireless LAN, with expanded communication capacity as the aim.

There are two possible methods of AP selection in a wireless LAN consisting of two or more APs: autonomous distributed AP selection by the STA based on information obtained by the STA, and centralized control by the wireless LAN, which assigns the STA to the optimal AP. Centralized control may be implemented by linking the AP and the STA based on information collected by the wired equipment connected with wireless LAN in such a way as to optimize a certain index. However, the current IEEE 802.11 standards can not associate STAs with specific APs selectively, and interconnectivity with existing wireless LAN terminals will pose a problem. On the other hand, with autonomous distributed AP selection, each STA selects an AP based on a specified algorithm. In a conventional wireless LAN, the STA determines the destination AP, performing autonomous distributed selection using the intensity of the received signal strength as the only index. However, STAs are often unevenly disposed in specific positions according to the physical positions of furniture such as sofas or desks, so that many STAs will concentrate at specific APs under this AP selection strategy. Consequently, if an STA connects to the AP based on the received signal strength, the user will instead be faced with reduced throughput, as throughput per STA will decrease for all users, resulting in a failure to provide efficient and equitable use of radio resources [1]-[4].

Taking compatibility with existing methods and facility of implementation into consideration, we propose a method in which the STA performs autonomous distributed AP selection based on information obtained from the wireless LAN [5]. The AP selection strategy is to connect the STA to the AP that is expected to provide the highest throughput. This paper describes the basic characteristics of the proposed method studied to date and shows that this method makes more efficient and equitable use of wireless resources than conventional methods.

2.2 Distributed AP selection scheme

The proposed autonomous distributed AP selection scheme consists of two functional elements: an algorithm according to which the STA selects the AP, and a mechanism to execute the algorithm regularly, permitting dynamic selection of the AP best suited to the purpose at hand. This section provides an outline of these elements.

2.2.1 AP selection algorithm

If the intensity of the received signal strength is chosen as the index, as is the case with conventional methods, the AP selection of the STA will depend on physical positioning; this leads to the disproportionate focus of many STAs on specific APs, reducing throughput. We have therefore proposed an AP selection algorithm that enables each STA to predict potential throughput expected for each AP and then select the AP expected to provide the highest throughput when STAs enter the wireless LAN. As this algorithm operates to maximize the throughput of the STA on which it is running, it is defined as the Maximizing Local Throughput (MLT) algorithm. The MLT obtains the expected throughput as follows. As shown in Reference[6], in ideal conditions without collisions or transmission errors, the time, t_T , required to transmit a packet (measured in bits) is obtained from the following equation:

$$t_T = RTS + CTS + \frac{Data(bits)}{Rate(b/s)} + ACK + DIFS + 3SIFS \quad (1)$$

Here, when the Packet Error Rate (PER) of the wireless link between the STA and the AP is P , the average transmission time, T_w , required to transmit and receive a packet correctly is expressed as the following equation:

$$T_w = t_T + \sum_{i=1}^{\infty} P^i * (1-P) * i * t_T = \frac{t_T}{1-P} \quad (2)$$

If the effect of collisions between STAs is negligible, N STAs use equivalent portions of the wireless resources provided by the AP. Thus, the throughput, θ , of each STA is

expressed as the following equation:

$$\theta = \frac{Data}{T_w} = \frac{Data * (1-P)}{t_T * N} \quad (3)$$

Assuming that the sizes of the packets transmitted and received by each STA are the same, Equation (3) can be expressed as follows:

$$W_{MLT} = \frac{(1-P)}{N} \quad (4)$$

The PER expressed with P in Equation (4) can be obtained from the intensity of the received signal strength. N is the number of STAs connected to the AP for communication. To provide this N value to each STA, the AP needs to add information on the number of STAs accommodated by the AP to the Probe Response and Beacon frames. The STA obtains this information through the scanning process. Here, conventional terminals ignore the added information, so they require no modification. With Equation (4) as the weight function, the STA selects the AP for which this function is at maximum. In this manner, each STA selects the AP to maximize throughput.

2.2.2 Dynamic AP selection mechanism

When each STA joins the wireless LAN, the STA selects an AP according to the MLT algorithm, as described in the previous section. However, connection of another STA or change in the wireless environment may change the optimal AP. To account for this change, the proposed AP selection method executes the AP selection algorithm regularly via the dynamic AP selection mechanism, again selects the optimal AP in accordance with the change in conditions, and performs roaming.

Here we will provide an outline of the AP selection scheme based on the state transition diagram indicated in Fig.1. The proposed dynamic AP selection mechanism governs transitions between three states: search, re-search, and idle. First, the STA calculates the weight function for all APs in the Search

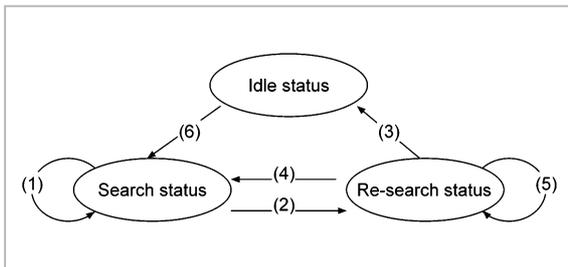


Fig. 1 Dynamic AP selection mechanism

Interval (1). If the weight function is largest for a new AP (AP_{new}) that differs from the AP to which the STA is currently connected, the STA moves to the re-search state (2). In this state, the STA calculates the weight function of all APs again after the Backoff Time. The Backoff Time is randomly selected from 0 to 1. If AP_{new} is selected again as the optimal AP in the recalculation, the STA roams to AP_{new} , and moves to the idle state (3). If the currently connected AP is selected, the STA returns to the search state (4). If another AP is selected as the optimal AP, the STA remains in the re-search state (5). The new AP is selected as AP_{new} , and the STA recalculates the weight function for all APs after the Backoff Time has again elapsed. The STA that roamed to the new AP_{new} returns to the search state; this is done only after the Idle Time has elapsed, to prevent the so-called “ping-pong effect” (6).

2.3 Performance evaluation

This paper reports on the evaluation of computer simulation with a model containing 40 STAs communicating with the Source through four APs. Construction of the wireless LAN is assumed to be based on IEEE 802.11b, the wireless channels are set to avoid interference between APs, and the APs and STAs are placed as shown in Fig.2. The simulator is based on NS-2 for the VINT project and expanded to meet IEEE 802.11b requirements. The shadowing model is selected as the error model in the wireless section. The Source transmits the TCP packet to the 40 STAs through the router and the four APs. The SACK option for TCP is used with segment size set to 1,500 bytes. Each TCP flow contin-

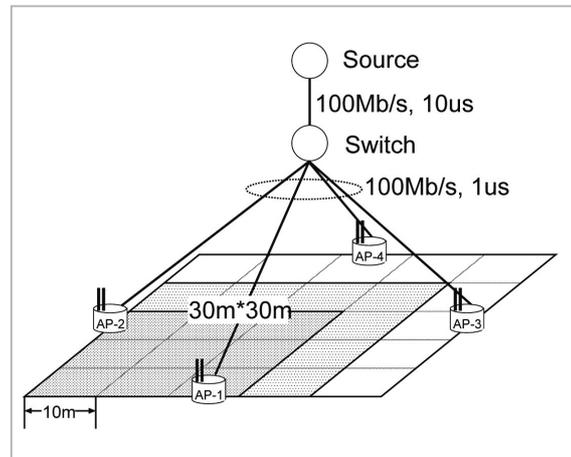


Fig. 2 Simulation model

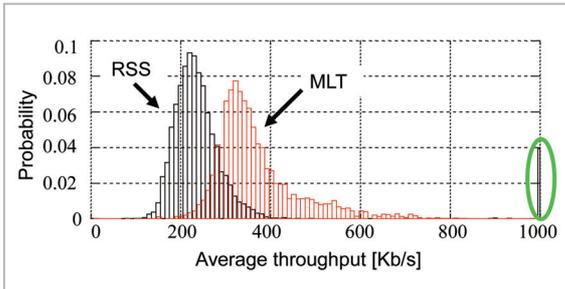
uously transmits a file containing non-terminating data. The wired link between the Source and the router is connected at a bandwidth of 100 Mb/s and a delay of 10 usec, and the wired links between the router and each AP are connected with a bandwidth of 100 Mb/s and a delay of 1 usec.

To include the uneven concentration of STAs at specific APs in the simulation, the STAs are placed evenly within an area of 30 m \times 30 m, as shown in Fig.2. This configuration tends to cause a concentration of STAs at AP-1 and AP-2 when APs are selected using conventional Received Signal Strength Indicator (RSSI). The 40 STAs are randomly configured in 10 seconds. Here, each STA selects an AP according to the AP selection algorithm. For the AP selection algorithm, both the proposed MLT and Received Signal Strength (RSS) based on conventional RSSI are used for comparison. The STAs are not moved from their initial positions.

Table 1 illustrates the throughput, and indicates that MLT significantly improves both minimum and average throughput. For detailed evaluation of the behavior of each algorithm, Figure 3 shows the distribution of average throughput. Figure 3 indicates that the RSS method results in a lower mode than the MLT. This is a result of selecting APs using the intensity of the received signal strength as the index, causing the STAs to concentrate at specific APs and suppressing throughput. On

Table 1 Throughput performance

	Minimum Throughput	Average Throughput
RSS	154.73 [Kb/s]	13.07 [Mb/s]
MLT	271.50 [Kb/s]	15.05 [Mb/s]

**Fig.3** Distribution of average throughput

the other hand, MLT selects APs such that each STA maximizes its throughput. Thus the mode and the minimum value are both higher than with RSS. These results indicate that the proposed autonomous distributed AP selection scheme can make more efficient use of wireless LAN resources relative to conventional methods.

This section focuses on wireless LAN access to the Internet and on an intranet managed by a single organization, showing that the wireless LAN resources are used equitably and efficiently when each terminal applies the proposed autonomous distributed AP selection scheme. However, many wireless access networks now overlap (as is the case with PHS and 3G networks), and it has thus become necessary to provide for communication schemes using two or more communication media. Section 3 discusses inter-domain technology for resource allocation and utilization in the case of pervasive ubiquitous networks, in which two or more access networks are used simultaneously.

3 Inter-domain access network selection method

This section slightly expands the target environment and focuses on the multi-home environment, where diverse access networks overlap and allow the user to make use of two or more access networks at the same time. To

provide high-quality and high-efficiency mobile communication in such an environment, the mobile host should support two or more network media, should select the optimal network medium according to network conditions and communication flow characteristics, and should be able to use these network media independently without disconnecting communication. Related methods already proposed elsewhere include Mobile IP (MIP)[7], Mobile Stream Control Transmission Protocol (Mobile SCTP)[8], and Host Identity Protocol (HIP)[9]. These protocols all provide mobility and multi-home functions but share a problematic lack of a mechanism to control Quality of Service (QoS). We have therefore proposed the Media Optimization Network Architecture (MONA)[10], which makes it possible to select and use the optimal network medium according to network conditions and flow characteristics, such as available bandwidth and required delay characteristics.

3.1 Media Optimization Network Architecture (MONA)

First, we will describe the concept behind the proposed network medium optimization method using the example shown in Fig.4. In this example, three hosts, α , β , and γ , are connected via the Internet. In such an environment, the access network features lower bandwidth, greater delay, and lower stability than the core network, so that the characteristics of the access network have a great impact on the QoS of the communication. In other words, the selection of these access networks is important in improving QoS, and yet conventional schemes force the user to continue to use the medium selected at the start of communication, even if the host supports two or more communication media; further, the user can only use a single medium at a time. MONA thus provides a mechanism for selecting and using the optimal medium for each communication flow according to flow characteristics and the status of the access networks, as shown in the example given in the figure. In order to select the optimal medium

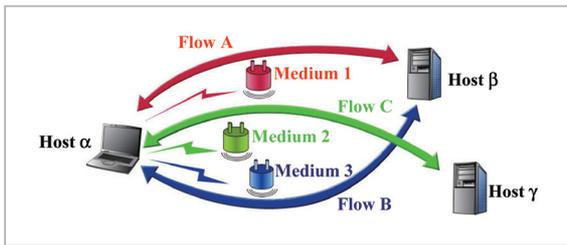


Fig.4 Concept behind network medium optimization

dynamically and to enable a switch to this medium even during communication, it is necessary to control the individual flow and media conditions continuously. When selecting the receiving medium, information regarding the received flow must also be passed to the corresponding host. To accomplish this, MONA adds an association layer to the existing network layer structure. This association layer serves as a new network layer for controlling flow and media information together.

This association layer is inserted between the transport and network layers, as shown in Fig.5. To select the network medium in each communication flow entails selection of the IP address used in communication controlled in the network layer (i.e., the third layer) for each communication flow that is itself controlled by the transport layer (i.e., the fourth layer). Thus, the association layer is inserted between these two layers as layer 3.5. This method does not require modification of the existing network layers, allowing for the use of conventional applications without modification. This method also has the advantage of easy accommodation of future transport protocols and wireless access technologies.

Next, we will explain the operational concept behind the use of the association layer. Figure 6 shows the relationship between the network layers. The association layer controls the set of virtual communication paths generated from the combination of the network media, i.e., IP addresses, of each host as an association. In this example, each host has two network media, so that there are four routes in the association. MONA assigns each transport flow between the hosts to the appro-

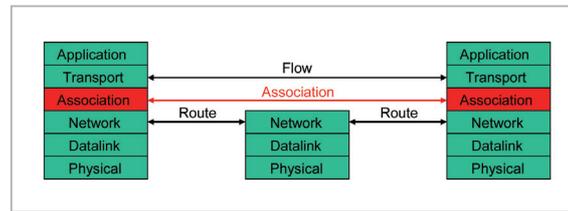


Fig.5 Association layer in the network layer structure

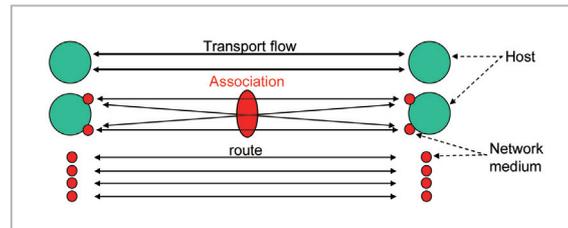


Fig.6 Relationship between the network layers

appropriate route in the association. Here, the association layer separates the transport layer identifier (for flow identification) and the network layer identifier (for packet transmission and receipt) and makes adjustments to these identifiers. In this manner, the association can be modified dynamically during communication in response to a change in the number of available media or to a change in IP addresses or network conditions (due to movement of the hosts). This inter-host association allows for optimization of network media without the need for installation of a special mechanism within the network.

To establish and control the association, the association layer also allows the hosts to exchange the required information, including the association layer identifier, medium addresses, and the media priority within each flow. For this operation, the association layer uses the Association Management Protocol (AMP). The minimal information required to identify the association is inserted as the AMP header between the IP header and the payload in each datagram that corresponds to the association. On the other hand, the information for managing the association is sent as an association packet independent of the data flow. This suppresses the header overhead and enables communication via conventional hosts without

the MONA mechanism, using ordinary TCP/IP and UDP/IP.

3.2 Performance evaluation

This section describes the results of computer simulation performed to evaluate the effectiveness and practicability of the proposed MONA, and discusses a demonstration experiment using prototype implementation. First, the simulator is developed based on NS-2, with the implementation of the association layer and the protocol. The target environment is the model shown in Fig.7, where the mobile host (MH) connects to the correspondent host (CH) via the cellular network and wireless LAN. Each link has the bandwidth and delay time indicated in the figure. The buffer size for each node is 50 packets. Here, neither interference nor transmission errors generated in the wireless link are taken into consideration. It is also assumed that the MH receives two flows from the CH: a 64-Kb/s UDP flow with an assumed IP phone, and a TCP flow receiving a non-terminating file. Packet size is 200 bytes for the UDP and 1,000 bytes for the TCP. The SACK TCP algorithm is used. The MH enters the wireless LAN area 30 seconds after the simulation is started and exits the area after another 30 seconds. Thus, the MH uses the multi-home environment for 30 seconds. Figure 8 and 9 show TCP throughput performance and UDP transmission delay characteristics, respectively. In the figures, MONA corresponds to the case in which only the TCP flow uses the wireless LAN through network-medium optimization when the wireless LAN is available. This is because the TCP flow requires wideband links whereas the UDP flow instead requires links without congestion. “Original” indicates the results for a case without the association scheme, for comparison; here the MH continues to use the cellular network. These figures indicate that the effective selection of access networks can provide high TCP throughput and can significantly reduce UDP transmission delay when different access networks are available.

Next, we will discuss the results of the

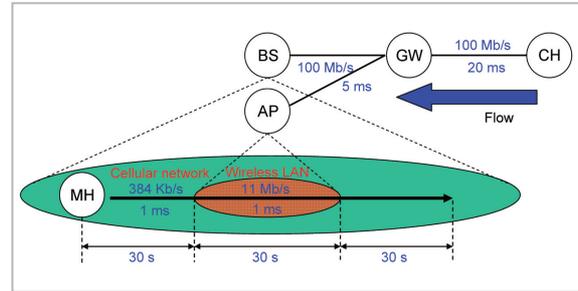


Fig.7 Simulation model

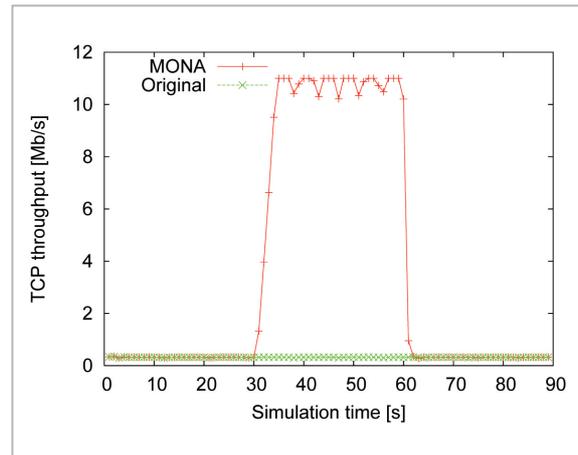


Fig.8 TCP throughput performance

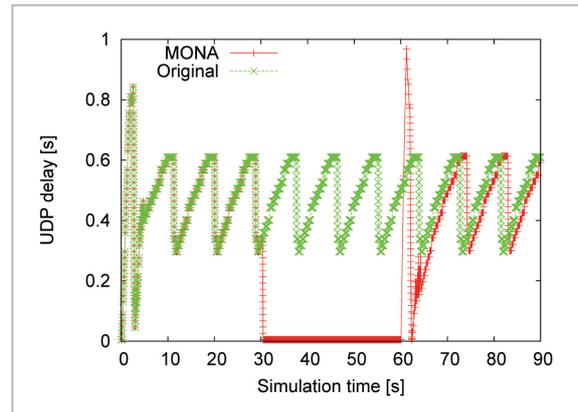


Fig.9 UDP transmission delay characteristics

demonstration experiment with prototype implementation. This prototype implements the basic functions of MONA in the Linux kernel, using a mechanism enabling continuous communication when the IP addresses of the communication media change or with a switch in communication media. The target environment is a model in which the MH, with two network media (wired and wireless LAN), connects to the CH via a router. Figure 10

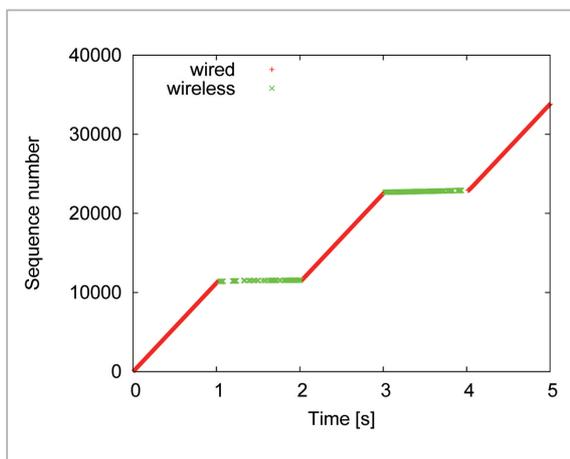


Fig. 10 Sequence number of received packets

shows the change in the received ACK packet sequence number during connection and disconnection of the wired LAN; this connection and disconnection process is repeated every second while the MH receives an iperf-based TCP flow from the CH. Figure 10 shows how MONA selects the appropriate communication medium according to network conditions and continues communication without disconnec-

tion.

4 Conclusions

This paper introduces new proposed methods for dynamic, adaptive technologies for resource allocation and utilization of access networks, addressing aspects of both intra-domain and inter-domain techniques. It also describes the effectiveness of the proposed methods, as demonstrated in computer simulations and experiments involving prototype implementation. We conclude that the inter-domain and intra-domain techniques for resource allocation and utilization in each access network will, when combined, improve the QoS of end-to-end communication passing through the access networks and promote the efficient use of limited resources. In the future, we will expand the scale of the target access networks, including multi-hop wireless networks, and will develop methods that can be combined with transport protocols and routing technology.

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