LOHAS: LOad balancing with fast HAndoff Scheme on smartphones over IEEE 802.11 WLANs

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ABSTRACT

This paper presents a new scheme, *LOad balancing with fast HAndoff Scheme* (LOHAS), for IEEE 802.11 Wireless Local Area Networks (WLANs) that reduces handoff delay and at the same time achieves load balancing among Access Points (APs). The key idea of LOHAS is in sharing AP information among Mobile Stations (MSs) and utilizing a sensor of smartphones. With LOHAS, MSs can reduce handoff delay by avoiding scanning the entire channels and also use traffic load of APs in the selection of the least loaded AP. LOHAS is implemented on a commercial smartphone and evaluated with field experiments, which show that LOHAS reduces the scanning delay of the handoff procedure by around 90% and improves network performance significantly in terms of network throughput and packet loss ratio. In addition, an experimentation on video streaming is performed in order to demonstrate the practicability of LOHAS. LOHAS can be applied without any modifications to APs conforming to IEEE 802.11 standard.

Categories and Subject Descriptors

C.2.1 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Architecture and Design—*Wireless communication*

Keywords

IEEE 802.11 WLAN; Load Balancing; AP selection; Handoff.

1. INTRODUCTION

The use of Mobile Stations (MSs), such as tablet PCs and smartphones, has increased tremendously in recent years, and the availability of real-time services on these devices has made our lives more convenient. Users can enjoy on-line banking, email, Voice over IP (VoIP) and video streaming services anytime and anywhere on these devices. These MSs can be used to provide useful on-line services through various types of wireless networks such as cellular networks and IEEE 802.11 Wireless Local Area Networks (WLANs). Since WLANs have several advantages over cellular networks, such as low cost of installation, ease of deployment and fast data transfer rate, they are widely deployed to support these on-line services as an alternative technology to cellular networks.

In order to accommodate the increasing demand for WLAN connections from MSs, network operators are deploying more and more Access Points (APs). However, this causes traffic load to be unevenly distributed because most off-the-shelf MSs rely on Received Signal Strength Indicator (RSSI) in the AP selection procedure. This leads to congestion in parts of the network, reducing network throughput. In addition, long latency during the handoff procedure causes service disruption for real-time applications, which is a serious problem that degrades user experience.

Therefore, this paper proposes a new method called *LOad balancing with fast HAndoff Scheme* (LOHAS) that achieves load balancing among APs and reduces handoff delay in WLANs based on collective intelligence of MSs. With LOHAS, MSs share the network information including the Basic Service Set Identification (BSSID), channel frequency, the relative location and traffic load of APs with other MSs. In order to get the relative location of APs, MSs utilize geomagnetic sensor embedded in smartphones. This information facilitates fast handoff and selection of the least congested AP.

To evaluate LOHAS, a prototype was implemented on commercial smartphones and field trials were conducted. Our experimental results show that LOHAS reduces scanning delay by 90% and significantly improves network performance in terms of throughput and packet loss ratio. In addition, an experimentation for video streaming service on LOHAS was conducted and, we confirmed that LOHAS improves the quality of video streaming service.

Achieving both fast handoff and load balancing is a fundamental issue of the WLANs, and this is the first paper that presents the scheme for solving the issue and proves its validity by implementa-

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tion on a commercial smartphone. The major contributions of this paper are as follows:

- Proposes a novel scheme which provides both load balancing and fast handoff in WLANs.
- Proposes a method that can be applied without any modifications of APs conforming to IEEE 802.11 standard.
- Implemented the method on a commercial smartphone and evaluated it with field experiments to show its efficiency and validity.

2. BACKGROUND AND RELATED WORK

This section presents the background, related work, and their limitations. The basic building block of an IEEE 802.11 WLAN is the Basic Service Set (BSS), which is a unit of network consisting of an AP and MSs. According to IEEE 802.11n standard, the signal coverage of an AP is around 100 meters. An MS sends and receives packets through the AP within this signal coverage and needs to hand off to another AP when it moves away from the coverage of the current AP. During the handoff procedure, MS cannot send and receive data packets. When an MS begins the handoff procedure, the MS performs *Scanning* to gather information of nearby APs, such as the BSSID and channel frequency of the AP. There are two scanning methods, *Active Scanning* and *Passive Scanning*. In *Active Scanning*, an MS finds APs by sending Probe Request frames on each channel. In *Passive Scanning*, each MS gathers AP information by listening to Beacon frames periodically transmitted by the APs. When an MS is connected, the MS also periodically performs background scanning, called *Periodic Background Scanning* (PBS) [12] in order to discover available APs in its vicinity.

Previous empirical analysis shows that the total handoff delay is around 300$\sim$500 ms [14], which is too long for real-time applications. For instance, VoIP requires an end-to-end delay to be less than 150 ms [5]. Thus, real-time applications will experience disruptions during handoffs.

The conventional approach to AP selection is based on RSSI of candidate APs. This may cause inefficient resource utilization because the AP with the strongest RSSI can be congested due to a large number of associated MSs, while other adjacent APs with lower RSSI are left under-utilized. As a result, MSs that select congested AP may need to hand off again in order to obtain more network resources.

2.1 Load balancing schemes

The main cause of the load balancing problem is the AP selection without consideration for the load of candidate APs. There have been many previous efforts to improve AP selection to evenly distribute load.

There are two types of schemes for load balancing, the MS-based approach and the network-based approach. In the network-based load balancing scheme, the network-side entity distributes MSs among APs to balance load of APs in the network. MSs passively modify their connections according to the decision made by the controller in the network side. In [16], APs exchange their load information and select the MS that must hand off to another AP in order to balance the load. In [7], APs send their load information to the designated server. The server monitors the load status of the network, and it makes decision on accepting new MS.

The network-based scheme requires the protocol modifications on the AP side, and all APs in the network should be equipped with additional software in order to make the scheme operate effectively.

Most of the MS-based schemes [8, 9, 13, 15] utilize additional information to select the least loaded AP among candidate APs. In [13], the authors pointed out that the difference between the sequence numbers of two successive Beacon frames is the number of packets processed by AP during the Beacon interval. They use the number of processed packets as the metric for AP selection. In [15], the estimated bandwidth that candidate APs can provide is used for AP selection. In [8], MSs use the round-trip-time from Probe Request to Probe Response on the basic of the analysis that the round-trip-time becomes longer as the load of AP becomes heavier. In [9], MSs utilize the potential hidden node effect of candidate APs to select next AP. The calculation of the potential hidden node effect of candidate APs is based on channel utilization of AP and channel busy ratio measured by MSs.

Since the above mentioned MS-based load balancing schemes focused on only measurement of the AP load, the approaches have a common limitation that they spend long time to gather additional information, such as Beacon frame delay, round-trip-time or channel busy ratio. Because an AP selection is one of the sub-procedures of the entire handoff procedure, their approaches end up increasing handoff delay.

2.2 Fast handoff schemes

Since scanning delay accounts for most of the handoff delay [14], most of the solutions for fast handoff are focused on reducing the scanning delay [10, 11, 17]. In [17], MS predicts user routes based on past user mobility patterns. The server provides information of APs located on the expected route of the user so that the MS can skip the scanning procedure. The authors in [10] suggest Directional Handoff scheme. MSs measure user direction of movement using geomagnetic sensor and scan only one or two channels of the APs in the direction of user movement. In [11], the server containing neighbor AP graph provides the list of nearby APs to MSs. MSs scan only channels of nearby APs and utilize Inter Access Point Protocol (IAPP) to transfer MS context information from the previous AP to the new AP in order to reduce the delay caused by the handoff procedure.

The handoff solutions above reduced handoff delay by limiting the number of channels to scan or by utilizing the AP usage history. However, they do not consider the load distribution when there are multiple available APs. These solutions might worsen the load balancing problem in densely-AP-deployed environments. In addition, the handoff solutions above are not effective when they are used in conjunction with the MS-based load balancing mechanisms mentioned above because the MS-based load balancing solutions increase handoff delay due to additional information gathering processes.

Reducing the handoff delay and load balancing are not separate issues and need to be considered together. However, previous works considered solutions of only one of the two problems, with the possible result of worsening the solution of the other problem. In order to support real-time multimedia applications requiring seamless connectivity and high bandwidth, a new solution resolving both problems is needed.

3. THE DESCRIPTION OF LOHAS

This section presents LOHAS scheme. LOHAS utilizes collective intelligence among MSs. A network information which MSs acquired while performing handoff is shared among MSs through a designated server. The information shared among MSs includes the BSSID of the previous AP, channel frequency, traffic load, the BSSID and a relative location of the new AP. The relative location of the new AP is a direction from the previous AP to the new AP,

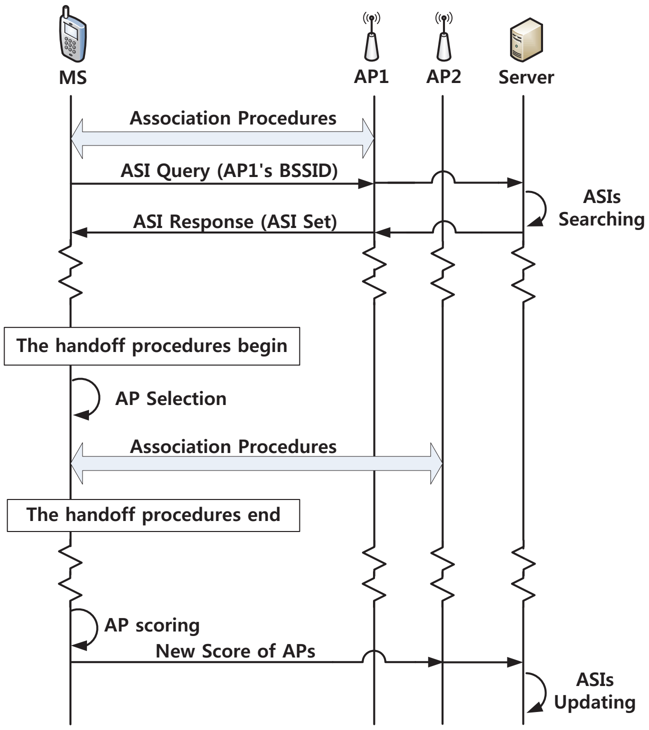


Figure 1: Handoff procedure of LOHAS.

and this is measured by MSs with a geomagnetic sensor. The MS that received this information from the server can get an available AP list with traffic load of the APs around the current AP.

As a unit of data including the network information, we define *AP Situation Information* (ASI) which consists of following fields (Note that information in these fields are described from the perspective of MS utilizing the ASI):

- *Current AP BSSID*: BSSID of the AP that an MS is currently associated with.
- *Direction*: The movement direction of an MS.
- *Next AP BSSID*: BSSID of the AP that is available in the direction indicated by the Direction.
- *Channel* and *Band*: The channel and the band of the AP indicated by Next AP BSSID.
- *Score*: The score that represents the traffic load of the AP indicated by Next AP BSSID.

Figure 1 shows how an MS receives ASIs from the server in detail. For better understanding, it is assumed that the server already has ASIs. In the figure, there are AP1 and AP2 around the MS. The MS initially makes a connection with AP1. After association with AP1, the MS sends an *ASI Query* with AP1's BSSID to the server. Then, the server retrieves ASIs containing nearby APs using AP1's BSSID and sends ASIs back to the MS through *ASI Response*. Instead of performing the scanning procedure, the MS gets candidate APs from received ASIs. Then, the MS selects the next AP based on the Score of ASIs. In Figure 1, let us assume that AP2 is chosen as the next AP and the MS makes new connection with AP2. After a successful association with AP2, the MS measures the load of AP2 and calculates a score based on the measured load. Newly

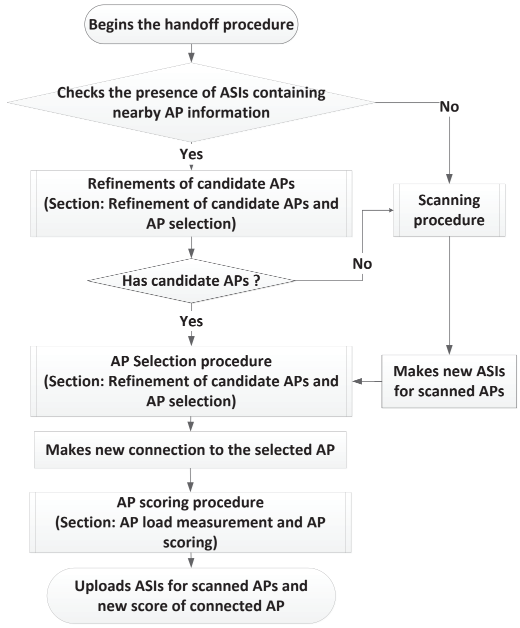


Figure 2: Flowchart of the handoff procedure of LOHAS.

calculated score is uploaded to the server using *ASI score update message*. If the MS has not performed handoff for a while, e.g., 5 minutes since the last reception of the ASI Response from the server, the MS sends the ASI Query again in order to have an up-to-date traffic load information.

3.1 The handoff procedure for MSs

When an MS sets up a connection with an AP, it receives ASIs of the nearby APs from the server. However, the server might have no information for some BSSs because of no activities of MSs in the network. Thus, the handoff procedure varies according to whether or not the MS received ASIs containing nearby AP information from the server. Figure 2 shows the handoff process of the MS in LOHAS. At the beginning of the handoff procedure, The MS checks whether the ASIs received from the server are empty or not. If they are empty, it means that the server has no ASIs for APs around the current AP. Then, The MS begins the active scanning procedure to obtain a list of available APs and stores them to create ASIs for the scanned APs after the handoff. If the MS has received ASIs for nearby APs, it gets the list of available APs from the ASIs. After getting the AP list from the scanning procedure or received ASIs, it extracts candidate APs that are reachable from the MS using the candidate AP refinement procedure (Section: Refinement of candidate APs and AP selection). Then, the MS makes new connection with the selected AP. Once new connection is set up, the MS calculates the score of newly connected AP (Section: AP load measurement and AP scoring). The calculated score is uploaded to the server in order to update ASIs in the server. If the MS has new ASIs made by itself for scanned APs, the ASIs are also uploaded to the server.

3.2 The function of the server

The server maintains the ASI Table as shown in Figure 3. It performs the following functions:

1. Constructs the ASI Table with ASIs uploaded by MSs.
2. Retrieves and provides ASIs that an MS requests. Figure 3 shows the ASI Table in the server and how the server provides

ASI Table

No.	Current AP BSSID	Direction	Next AP BSSID	Channel	Band	Score
••••••						
3	AP1 BSSID	1	AP2 BSSID	1	2.4G	244
4	AP1 BSSID	7	AP3 BSSID	6	5G	250
5	AP1 BSSID	5	AP4 BSSID	11	2.4G	234
6	AP1 BSSID	3	AP5 BSSID	6	2.4G	145
••••••						

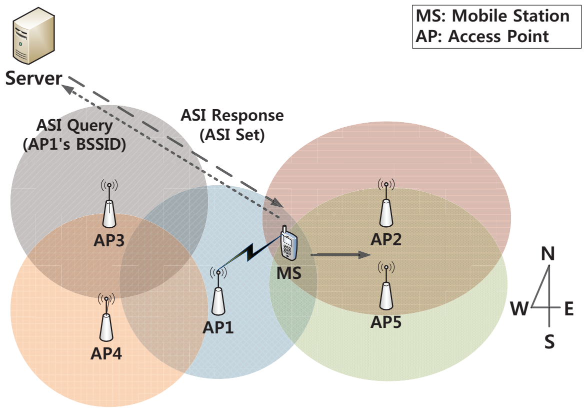


Figure 3: The ASI Table and interactions between the server and an MS.

the ASIs to an MS. In Figure 3, there are five APs (AP1, AP2, AP3, AP4 and AP5) around the MS, which is associated with AP1. To get the ASIs, the MS sends the ASI Query with the AP1's BSSID. When the server receives the ASI Query from the MS, the server looks for the ASIs that have AP1's BSSID in the Current AP BSSID field and sends back the ASI Response with the set of the searched ASIs to the MS. In Figure 3, the entries from 3 to 6 in the ASI Table are sent to the MS. These ASIs contain the information of adjacent APs of AP1.

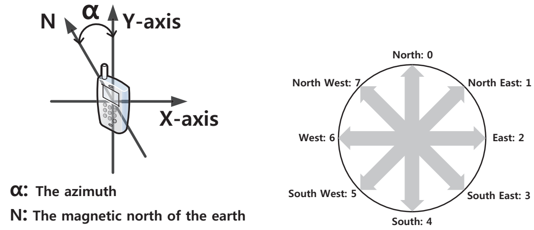
3. Updates the Score field of ASIs in the ASI Table. Since the load of APs changes over time, the server updates ASIs in the ASI Table by the ASI score update messages from MSs. The MSs send the ASI score update message to the server whenever they perform handoffs or detect changes in the scores of connected APs or nearby APs.

Note that the overhead for server management is negligible since the ASI Table is automatically constructed and updated.

3.3 Refinement of candidate APs and AP selection

In Figure 3, after MS obtains ASIs from the server, it learns that AP2, AP3, AP4 and AP5 are in its vicinity. However, not all APs may actually be reachable. This is because the MS is moving towards the east, but AP3 and AP4 are located on the opposite direction. Thus, the list of candidate APs is refined by only considering APs that are located along the moving direction of the MS.

The moving direction of an MS is obtained using the geomagnetic sensor embedded in smartphones and tablet PCs [10]. The geomagnetic sensor measures the azimuth of an MS, which is the



(a) The azimuth of MSs. (b) The direction value.

Figure 4: Direction measurement of MSs.

angle measured clockwise from the magnetic north of the earth to the y-axis of the MS as shown in Figure 4a.

The APs indicated by ASIs having the same or just adjacent direction are considered to be located along the moving direction of the MS. For example, in Figure 3, the direction value of the MS is 2 (east) as shown in Figure 4b. Thus, AP2 and AP5 are selected as candidate APs because the entries 3 and 6 in the ASI Table have direction values of 1 and 3, respectively. After the extraction of candidate APs located on the direction of the MS, the MS chooses the least loaded AP among candidate APs. To compare the traffic load levels of candidate APs, the MS uses the Score field of the ASI. The value in the Score field is lower when the AP is more loaded, thus the MS selects the AP with the highest score. Then, the MS sends a Probe Request on the channel of the selected AP in order to measure RSSI of Probe Response before making new connection. If RSSI is strong enough, then the MS sends an Association Request to connect with the selected AP. However, if RSSI is under a threshold value, then the MS tries to connect with the AP with the second highest score.

3.4 AP load measurement and AP scoring

In LOHAS, MSs measure the load of its currently associated AP and nearby APs after the handoff procedure in contrast with the previous MS-based load balancing schemes. It means that the AP load measurement process does not increase handoff delay and so any methods can be applied to LOHAS. In this paper, we utilize the BSS Load Element for measuring AP traffic load, which is an optional element of a Beacon frame and a Probe Response defined in IEEE 802.11-2007 standard [6]. Since Beacon frames are periodically transmitted by APs, an MS does not need to send a separate request to acquire the BSS Load Element. Instead, the MS calculates the AP's score when it receives Beacon frames from the associated AP or Probe Responses from nearby APs during performing PBS. By this way, the MS updates the scores of not only its current AP but also the nearby APs operating on other channels.

The BSS Load Element contains the Channel Utilization filed. It is the percentage of time that the medium has been busy, normalized from 0 to 255. Based on this field, AP score is defined as follows:

$$Score = PerfectScore - CU \quad (1)$$

where,
CU = Channel Utilization ($0 \leq CU \leq 255$),
PerfectScore = 255

Note that the score does not need to precisely represent AP load because it is used for just comparing the load of APs in the AP selection procedure. The Channel Utilization indicates the current traffic load of the AP. Thus, the score has higher value as the Channel Utilization becomes lower. If the calculated score changes more

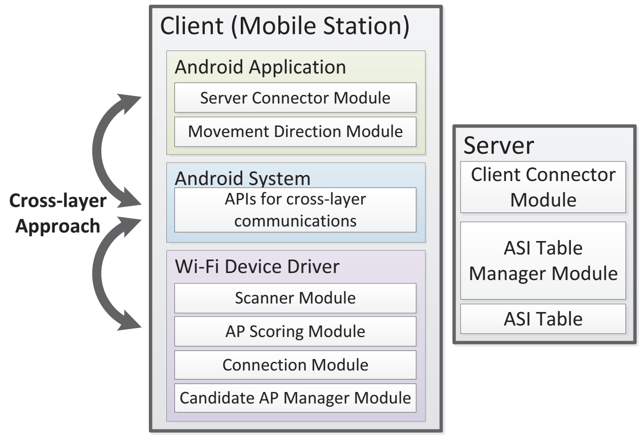


Figure 5: System structure of the implementation.

than 10%, then the MS sends an ASI score update message to the server so that the ASIs in the server can be updated.

4. IMPLEMENTATION AND EVALUATIONS

LOHAS was implemented on a commercial smartphone in order to prove its practicality. The prototype system was developed on Motorola Defy MB525 [3] running Android operating system [1]. Note that our scheme does not require changes to the functionality of existing APs.

Android platform provides Software Development Kit (SDK) for application development. It provides Application Programming Interfaces (APIs) for measuring the value of geomagnetic sensor and Socket programming functions for server communications. However, the SDK does not provide elaborate APIs to control processes of IEEE 802.11 WLANs such as the scanning or the AP selection procedure. Instead, they are implemented in the device driver. Thus, the main functions of LOHAS are implemented on the device driver. On the other hand, since LOHAS requires the upper layer services, such as passing ASIs from the server to the link layer, it is implemented using a cross-layer approach as shown in Figure 5. Several modules are implemented in the device driver and the application layer. Also added to Android system are the APIs for communications between implemented modules in the device driver and the application layer. The functional description of each module and interactions between modules are given in Table 1 and Figure 6.

4.1 Network performance experiments

In order to evaluate the effectiveness of LOHAS, an experimental environment was setup as shown in Figure 7 with three MSs and three APs running the IEEE 802.11g protocol. Each AP in Figure 7 operates on orthogonal channels and provides maximum throughput of 10 Mbps, which is specially configured for the experiments for the sake of simplicity. In order to measure the throughput and the packet loss ratio during the experiments, Iperf [2] was used. It supports two modes; client and server mode. All the MSs in Figure 7 operate in the Iperf client mode and generate fixed-size User Datagram Protocol (UDP) segments of 1,470 bytes at a Constant Bit Rate (CBR) to the Iperf server. All the APs, the Iperf server and LOHAS server containing ASI Table are connected by a switch. The detail specification of the experiments is described in Table 2.

The experiments begin with MS1 moving towards AP2 and AP3. From the point-of-view of MS1, AP2 is closer than AP3. Therefore,

Table 1: Function of modules.

	Item	Information
Server	Client Connector Module	Provides interfaces for communicating with client
	ASI Table Manager Module	Manages ASI Table
Client	Server Connector Module	Provides interfaces for communicating with server
	Movement Direction Module	Traces moving direction of the MS with the geomagnetic sensor
	Candidate AP Manager Module	Manages ASIs and selects AP
	Scanner Module	Scans channels, generates ASIs for scanned APs and uploads them to server
	Connection Module	Makes new connection to the AP given by Scanner Module
	AP Scoring Module	Calculates new score of APs and uploads new AP score to the server

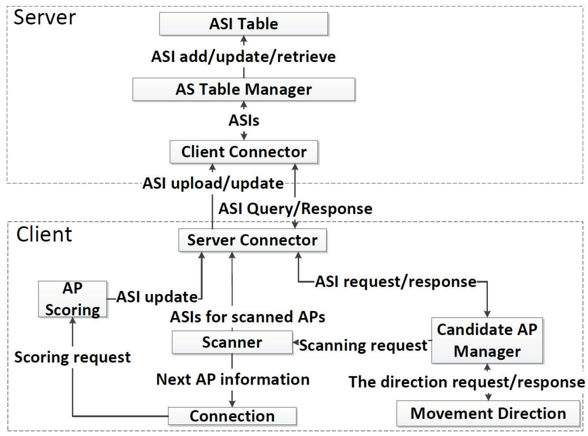


Figure 6: Interactions between modules.

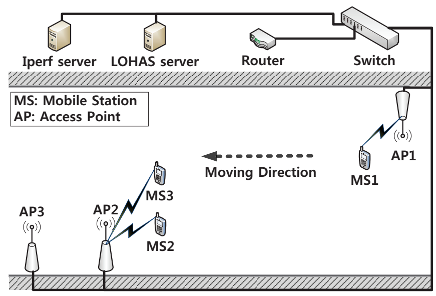
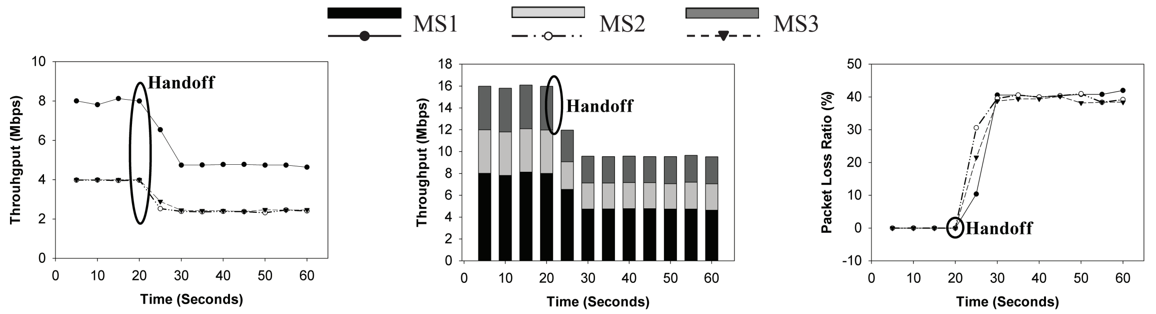


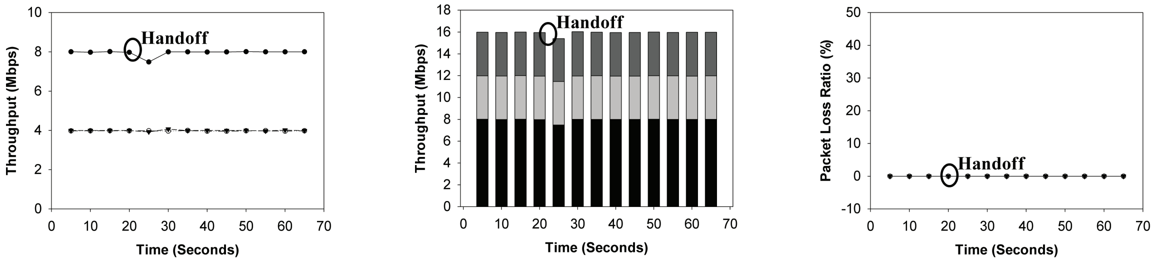
Figure 7: Setup for network performance experiments.

signal strength of AP2 is stronger for MS1 than that of AP3. The experiments consist of the following scenarios:

- Scenario 1 - MS1 uses the conventional method.
- Scenario 2 - MS1 uses LOHAS system, and the ASI Table has ASIs of AP2 and AP3.



(a) Scenario 1: Individual throughput (b) Scenario 1: Network throughput (c) Scenario 1: Packet loss ratio



(d) Scenario 2: Individual throughput (e) Scenario 2: Network throughput (f) Scenario 2: Packet loss ratio

Figure 8: Analysis of the network performance experiments.

In all scenarios, MS2 and MS3 are stationary and use the conventional method.

Figure 8a shows the throughput of each MS in Scenario 1. Before the handoff of MS1, the throughput of MS2 and MS3 is 4 Mbps. After MS1 changes its connection from AP1 to AP2, throughputs of MS2 and MS3 decrease to around 2 Mbps. The throughput of MS1 also drops to around 4 Mbps. This is because the sum of generated traffic from MS1, MS2 and MS3 exceeds the maximum capacity of AP2. Figure 8b shows the total throughput of the network. At the beginning stage of the experiment, the sum of throughputs of all MSs is 16 Mbps. After MS1 performs the handoff, the total throughput drops to around 10 Mbps. When MS1 selects its next AP, MS1 considers only RSSIs of candidate APs, thus AP2 is chosen by MS1 even though it already has two MSs generating traffic. As a result, AP2 becomes congested while AP3 is not utilized, which leads to inefficient utilization of resources. In addition, as can be seen in Figure 8c, packet loss ratio increases after MS1 performs the handoff.

In Scenario 2, MS1 changes its connection from AP1 to AP3. When MS1 performs the handoff, it obtains ASIs from the LOHAS server and therefore skips the scanning procedure. The AP2's score is lower than that of AP3 because MS2 and MS3 are already consuming resources of AP2. Based on the scores of AP2 and AP3, MS1 selects AP3 for re-association even though AP3 has lower RSSI than that of AP2. As can be seen in Figure 8d, MS2 and MS3 maintain around 4 Mbps of the throughput during the experiment. There is only little reduction in the throughput of MS1 when the handoff is occurred. The total network throughput stays at around 16 Mbps in Figure 8e. Moreover, as shown in Figure 8f, there is no packet loss of MSs.

Table 3 compares handoff delays of the two methods. The scanning delay of the conventional method is 144 ms, while that of LOHAS is only 14 ms. In Scenario 1, MS1 uses conventional handoff and so scans all channels to acquire nearby AP information. In Scenario 2, MS1 gets AP information from ASIs and avoids scanning the entire channels.

Table 2: Specification of network performance experiments.

Item	Information
MS1	HTC Nexus One
MS2	Samsung Nexus S
MS3	Motorola Defy MB525
AP1 $\sim$ AP3	IPTime N704A
MinChannelTime	6.5 ms
MaxChannelTime	11 ms
Radio type	IEEE 802.11g
Channels	1, 6 and 11 in 2.4 GH band
Max. capacity of APs	10 Mbps
CBR sending rate of MS2 and MS3	4 Mbps
CBR sending rate of MS1	8 Mbps
CBR packet size	1,470 Bytes
Transport layer protocol	UDP
UDP buffer size	108 Kbytes
Handoff threshold	-70 dBm
AP connection threshold	-75 dBm
RTS/CTS	Disabled

Table 3: Average handoff delay.

Methods	Scanning delay	Handoff delay
Conventional method	144 ms	220 ms
LOHAS	14 ms	89 ms

Table 4: Specification of video streaming experiments.

Item	Information
Radio type	IEEE 802.11b
Max. capacity of APs	6.8 Mbps
CBR sending rate from Iperf server to MS2	6.6 Mbps
CBR sending rate from Iperf server to MS3	4 Mbps
CBR packet size	1,470 Bytes
Video delivery protocol	RTP
Video bitrate	384 kbps
Frame rate	25
Frame width and height	480X320
Video length	10 minutes
Video codec	H.264 AVC

4.2 Video streaming experiments

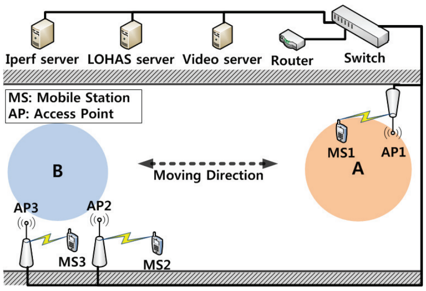


Figure 9: Setup for video streaming experiments.

In order to support real-time multimedia services for mobile devices, it is essential to provide sufficient bandwidth and short end-to-end delay. Because LOHAS allows an MS to handoff more quickly and select an AP which has more bandwidth than others, we conducted video streaming experiments to evaluate the effect of LOHAS on the Quality of Service (QoS) of video streaming.

The experimental environment was setup as depicted in Figure 9. MS1, MS2 and MS3 are connected with AP1, AP2 and AP3, respectively. Both MS2 and MS3 are stationary and receive UDP segments at a CBR of 6.6 Mbps and 4 Mbps from the Iperf server, respectively. For the simplicity of the experiments, all APs and MSs are running the IEEE 802.11b protocol. The detail specification of the experiments is described in Table 4. The experiments consist of two scenarios. Scenario 1 is for the conventional method used by MS1, and Scenario 2 is for LOHAS. Once the experiments begin, MS1 starts to receive video streaming and moves to the area B after 10 seconds. In the area B, there are AP2 and AP3. MS1 changes its connection from AP1 to either AP2 or AP3 while moving to the area B. From the point-of-view of MS1, AP2 has higher RSSI than AP3, and AP2 is more loaded. After the handoff, MS1 stays 60 seconds in the area B and goes back to the area A. MS1 repeats this movement until the end of the video. In order to compare the quality of the videos received by MS1 in two scenarios, Peak Signal-to-Noise Ratio (PSNR) [4] is measured. It represents the difference between an original video frame and its received one, and it is calculated for each frame of the decoded videos that MS1 received. Note that the original video used for PSNR calculation in the experiments is already encoded by the video server. The reason of using this video file as the original video is to exclude the PSNR drops caused by video encoding from PSNR calculation. Therefore, the PSNR is 100 dB unless there is a packet loss or error during video transmission. This way enables us to measure video quality changes caused by only network performance changes because no process affects PSNR except the video transmission.

In Scenario 1, MS1 moves to the area B and hands off to AP2 because RSSI of AP2 is higher than that of AP3. After the handoff of MS1, AP2 becomes too loaded with traffic for MS1 and MS2. Therefore, MS1 cannot get enough bandwidth for receiving the video streaming service and the quality of the received video deteriorates. As can be seen in Figure 10a, the PSNR graph of the received video has many parts with PSNR lower than 20 dB. The frames having PSNR lower than 20 dB has low quality as can be seen in Figure 10b. It is difficult to continue video streaming service in Scenario 1 because of too many damaged video frames.

In Scenario 2, MS1 selects AP3 when it moves to the area B although RSSI of AP3 is lower than that of AP2. This is because MS1 knows that AP3 is less loaded than AP2. Because AP3 has enough bandwidth, MS1 can continue to the video streaming service after the handoff to AP3. The quality of the received video deteriorates only during the handoffs as shown in Figure 10c.

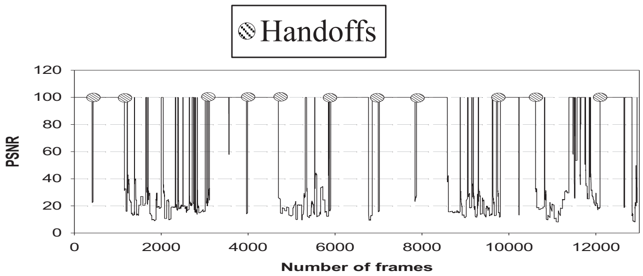
Table 5: Comparative analysis on received videos.

	Scenario 1: Conventional method	Scenario 2: LOHAS
Frame losses	9 %	3 %
Damaged frames	43 %	2 %
Average PSNR	65.8 dB	98.5 dB
Frames having PSNR lower than 20 dB	26.0 %	0.6 %

The comparative analysis on the videos received by MS1 in two scenarios is shown in Table 5. In Scenario 1, 9 % of frames are lost while only 3 % of frame losses in Scenario 2. This is mainly because the handoff delay of LOHAS is shorter than that of conventional method. As the handoff delay becomes longer, the number of lost frames increases since an MS cannot receive video data during the handoffs. The percentage of damaged frames is also significantly reduced in Scenario 2 because MS1 using LOHAS hands off to AP3 rather than AP2 that is highly loaded. Therefore MS1 using LOHAS gets enough bandwidth for video transmission after the handoffs. We proved that LOHAS improves network performance as well as the quality of video streaming service by the experiments. Since the number of MSs may fluctuate in real environments, simulation is needed to study such aspects and to look into the scalability of the server side.

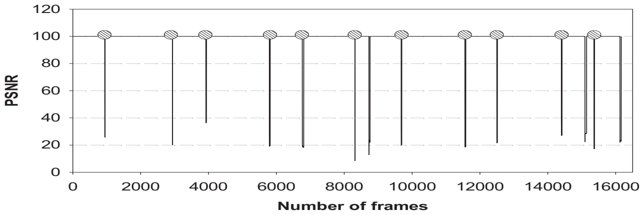
5. CONCLUSION AND FUTURE WORK

This paper proposes a new scheme, LOHAS for IEEE 802.11 WLANs, which achieves both fast handoff and load balancing based on collective intelligence of MSs utilizing geomagnetic sensor. In LOHAS, AP information sharing allows MSs to avoid scanning the entire channels during the handoff. MSs also refer AP load information in AP selection procedure so that it can select the least congested AP. LOHAS does not require any modifications of the IEEE 802.11 standard or the existing APs. In order to show the practicality and the effectiveness of the scheme, LOHAS was implemented on a commercial smartphone and field experiments were conducted. The experimental results show that LOHAS significantly reduces handoff delay and improves WLANs performance in terms



(a) Scenario 1: PSNR graph

(b) Scenario 1: Frame No. 1466



(c) Scenario 2: PSNR graph

(d) Scenario 2: Frame No. 1542

Figure 10: Analysis of the video streaming experiments.

of throughput and packet loss ratio as well as the QoS of video streaming on mobile devices.

LOHAS is expected to improve network performance as well as the QoS of mobile applications, such as real-time multimedia services that require seamless network connection and high bandwidth. In LOHAS, the server maintains an up-to-date network traffic profile by AP information uploads from MSs. As a result, LOHAS can be more effective in distributing loads among APs where network traffic can fluctuate.

As part of future work, we are investigating various AP load measurement methods and scoring systems for different types of traffic such as video, voice and text in order to make optimized AP selection for applications running on MSs. The error rate of selecting the least loaded AP or measuring moving direction of MSs also will be studied with the effect of the error on the performance of MSs. Also, we have a plan to simulate the scalability of the server side.

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