AFSO: An Adaptative Frame Size Optimization Mechanism for 802.11 Networks

Xiaohu Ge[1], Cheng-Xiang Wang[2], Yang Yang[3], Lei Shu[4], Chuang Liu[1] and Lin Xiang[1]
[1] Department of Electronics and Information Engineering, Huazhong University of Science and Technology
Wuhan, Hubei, 430074 – P.R.China
[e-mail: xhge@mail.hust.edu.cn]
[2] School of Engineering and Physical Sciences, Heriot-Watt University
Edinburgh EH14 4AS – UK
[e-mail: cheng-xiang.wang@hw.ac.uk]
[3] Shanghai Research Center for Wireless Communications (WiCO),
Shanghai Institute of Microsystem and Information Technology
Shanghai 200335 – P.R.China
[e-mail: yang.yang@shrcwc.org]
[4] Department of Multimedia Engineering, Graduate School of Information Science and Technology
Osaka University, Japan.
[e-mail: lei.shu@ieee.org]
*Corresponding author: Xiaohu Ge

Received May 18, 2010; revised May 27, 2010; accepted June 2, 2010;
published June 30, 2010

Abstract

In this paper, we analyze the impact of different frame types on self-similarity and burstiness characteristics of the aggregated frame traffic from a real 802.11 wireless local area network. We find that characteristics of aggregated frame traffic are affected by both mean frame size and the proportion of specified frame types. Based on this new knowledge, an adaptative frame size optimization (AFSO) mechanism is proposed to improve the transmission efficiency by adaptively adjusting data frame size according to the proportions of different frame types. Simulation results show that our proposed mechanism can effectively regulate the burstiness of aggregated frame traffic and improve the successful delivery rate of data frames when a fixed throughput target is set for 802.11 wireless networks.

Keywords: 802.11 wireless local area networks, frame traffic, self-similarity, burstiness

---

This research was supported by the National Natural Science Foundation of China (NSFC), contract/grant number: 60872007; National 863 High Technology Program of China, contract/grant number: 2009AA01Z239; The Ministry of Science and Technology (MOST), China, International Science and Technology Collaboration Program, contract/grant number: 2009DFB13080,0903; RCUK for the UK-China Science Bridges Project: R&D on (B)4G Wireless Mobile Communications; Grant-in-Aid for Scientific Research (S)(21220002) of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

DOI: 10.3837/tiis.2010.06.001

1. Introduction

The past decade has witnessed the great success story of IEEE 802.11 Wireless Local Area Networks (WLANs), which have been deployed and used by millions of users worldwidely. It is very important to investigate and understand the performance and behavior of 802.11 wireless networks in real world, which mainly depends on a network's traffic pattern and characteristics [1][2][3]. Therefore, real network traffic measurement and characteristics analysis are the keys to develop an accurate traffic model and a series of efficient optimization mechanisms for system performance improvement [4][5][6].

Most previous work was based on the traffic traces collected at the wired segments of Access Points (APs) by using periodic Simple Network Management Protocol (SNMP) queries of AP Management Information Bases (MIBs) [7][8][9], which are identified as the IP packet traffic. In [10], wireless IP packet traffic is collected from an Ad Hoc network and investigated to validate the self-similar property in this wireless IP traffic trace. These traces, however, do not record the traffic observed "in the air" and are lack of some important information in Media Access Control (MAC) layer. According to the IEEE 802.11 standards [11], all frames in the MAC layer are categorized into management, control and data frames. The management and control frames need not to be sent to the network layer, so the data contained in these frames never exists in the IP packet traffic traces. In addition, the data frames in the MAC layer contain both successful and unsuccessful data (re)transmissions. The latter, however, do not exist in the IP packet traffic traces. As a result, the characteristics of IP packet traffic can not reflect the real behaviors of 802.11 wireless networks in the air and we need to analyze the MAC-layer frame traffic to fully evaluate and understand the real performance and behaviors of 802.11 wireless networks.

Recently, some related work on the MAC-layer frame traces has been reported in [12][13][14][15][16]. Specifically, the 802.11 WLAN frame traffic was analyzed in [12]. It was found that retransmission and management frames account for about 38% of the total frame traffic. Management and control frames are together called overhead frames, which account for 54% of the total frame traffic. The frame loss process in an 802.11 wireless network was studied in [13] and some possible causes of intermediate frame loss were identified and discussed. The correlation between traffic congestion and data link layer properties, such as retransmission frames, frame sizes and data rates, was investigated in [14]. Some ideas and new schemes for improving network performance were proposed in [15]. In [16], we studied aggregated frame traffic collected from a real 802.11 wireless network and identified the second-order self-similar characteristic in frame traffic.

Some traffic control schemes based on multiple priority levels have been studied and widely used in 802.11 networks [17][18][19]. For instance, an Asymptotically Optimal Backoff (AOB) traffic control mechanism was proposed to improve the channel utilization based on the slot utilization and the average frame size inWLANs [18]. In [19], Nitin et al. developed a fully distributed algorithm for scheduling packet transmission such that different flows are allocated specific bandwidths in proportion of their weights. Packet transmission was then realized by choosing an appropriate backoff interval for a packet. When traffic load is increasing, some traffic control schemes stoped the exceeding traffic joining an 802.11 network [20][21]. Besides these traffic control schemes, some other schemes were developed for managing additional traffic in the wireless networks [22][23][24]. Yuxia Lin et al. proposed an admission control algorithm for multi-hop 802.11e-based WLANs, wherein a contention graph was used to determine whether a new flow should be admitted or not [22]. Didi Fedoua et al. provided a class based dynamic admission control algorithm for 802.11 WLANs, which adapted to the situation of the BSS (Basic Service Set), such as the global load and number of best effort Access Category (AC) [23]. In [24], an intelligent MAC model for traffic scheduling at the Quality of Service (QoS) enhanced access point was proposed. This model took into account the requirements of traffic streams and current system status to ensure QoS-provision for current users.

The above related work concentrated on the aggregated frame traffic consisting of management, control and data frames, whose individual impacts on the overall traffic characteristics and system performance are unknown and therefore the focus of this research. Specifically, this paper fully investigates the impacts of different types of frames on the characteristics of the aggregated frame traffic, which is collected at some international conferences. Our analytical results show that the impact of different types of frame traffic on the burstiness and self-similarity of aggregated frame traffic is simultaneously related to their mean frame sizes and proportions. Based on this result, an adaptative frame size optimization (AFSO) mechanism is proposed to decrease the burstiness of frame traffic and improve the transmission efficiency in the 802.11 wireless networks. All of these results increase the knowledge on the insight of frame traffic characteristics and relationships among different types frame traffic, furthermore, provide some practical guidelines for developing new efficient protocols to improve the common medium utilization and system throughput performance.

The rest of the paper is organized as follows. In Section 2, the frame type and measurement environment are introduced first, and then the main statistical characteristics of frame traffic are described. The impact of different types of frame traffic on the statistical characteristics of the aggregated frame traffic is analyzed in Section 3. The network model and configured parameters are illustrated in Section 4. Furthermore, a new AFSO mechanism is proposed in Section 5, and the simulation analysis of the new mechanism is discussed in Section 6. Finally, Section 7 concludes this paper.

2. Primary Knowledge

The symbols and variables in this paper are illustrated in the following **Table 1**.

Table 1. The symbols and variables table

Symbols and variables	**Specification**
$Z(t)$	The Random vector
a	The rescaled value
H	The Hurst parameter
x	The large value
$P[X]$	The probability distribution
α	The burstiness characteristic parameter
c	The constant
$\Delta_{Hurst,\,frame\_type}$	The self-similarity impact parameter
$\Delta_{\alpha,\,frame\_type}$	The burstiness impact parameter
X	The random variable
Y	The random variable

$frame\_type$	The type of frame traffic
$time\_scale$	The time scale used for measuring the frame traffic
$aggregated\_frame$	The variable value measured from the total frame traffic
data_frame_size	The current data frame size
upper_limit_size	The upper limit of data frame size
lower_frame_size	The lower limit of data frame size
$O(n)$	The complexity of algorithm

2.1 Frame Type and Data Collection

According to the IEEE 802.11 standard [11], there are three basic frame types, i.e. management frame, control frame and data frame. Each frame type has several defined subtypes to execute the corresponding functions. For instance, the management frame type consists of association request and response frame, reassociation request and response frame, disassociation frame, authentication and deauthentication frame, probe request and response frame, and beacon frame. The control frame type includes Request-to-Send (RTS) frame, Clear-to-Send (CTS) frame, and Acknowledgement (ACK) frame. The data frame type includes data frame, null function frame, and so on. Besides these three basic frame types, there is a special frame type, i.e. retransmission frame, which is the transmission failure frame in the management frames or data frames. This paper focuses on the characteristics of these three basic frame types.

The frame traffic collection environment is an open wireless network at the 7th Symposium on Operating Systems Design & Implementation (OSDI) conference held in Seattle, WA, USA, from November 6 to 8, 2006. This wireless network comprising 5 APs was deployed on one floor, operating in the IEEE 802.11b infrastructure mode on three non-overlapping frequency channels [25].

2.2 Characteristics of Frame Traffic

According to the studies in the network traffic [4][5][6][7], the self-similarity and burstiness of network traffic are two primary statistical characteristics regulated the frame traffic in the wireless networks. Therefore, we briefly describe these two statistical characteristics as follows.

A. Self-similarity

Self-similarity, in a strict sense, means that the statistical properties (e.g., all moments) of a random process do not change for all aggregation levels [26]. That is, the random process “looks the same” if one zooms in time “in and out” in the process. In this paper, we define the self-similarity as follows,

Definition 1: For any random vector of $Z(t)$ at different times has a joint distribution which is identical to that of a rescaled and normalized version of the random vector, thus $Z(t)$ is slef-similarity. For one-dimensional distributions, this is simply

$$Z(t) \overset{d}{\square} a^{-H} Z(at)\,, \tag{1}$$

where a is the rescaled value, and $H \in [0,1]$ denotes the self-similarity characteristic parameter or the Hurst parameter.

In reference [27], it is identified that larger values of H correspond to stronger self-similarity, which makes the aggregated process looks more similar with the original process.

B. Burstiness

Burstiness, a significant frame traffic characteristic in wireless networks, means the lack of smoothness. There are two kinds of burstiness, i.e. temporal burstiness and amplitude burstiness [28][29]. The former is derived from the long time dependence and can be described by the self-similarity parameter. The latter presents the fluctuation degree of frame traffic in short time scale, which can be denoted by the heavy-tailed property. Heavy-tailed property represents a power-law behavior in the tail of the distribution of a random process. In this paper, we will focus on the amplitude burstiness of frame traffic, and the burstiness is regarded as the amplitude burstiness if without any specification. Therefore, we define the burstiness as follows,

Definition 2: For a large value x, a probability distribution $P\left[X\right]$ is burstiness with index $0<\alpha<2$ if the tail of the distribution follows a power-law

$$P\left[X>x\right]\propto cx^{-\alpha}, \tag{2}$$

c is a constant, smaller values of α correspond to stronger burstiness. So α is called the burstiness characteristic parameter in this paper.

Burstiness property, by definition, implies that a “large” portion of the probability mass moves to the tail of the distribution, as α decreases. It means some small probability events cannot be ignored in the total distribution of the random process. In the sense of network traffic, the rare burstiness frame traffic can seriously impact the statistical characteristics of the total frame traffic.

3. Characteristics Analysis of Frame Traffic

In order to investigate the impact of self-similarity and burstiness on the different types frame traffic, some real wireless frame traffic traces were collected for measuring and analyzing. Firstly, we measure and analyze the frame traffic collected from the 7th OSDI conference, which was held from November 6 to 8, 2006 and each day was divided into morning, afternoon and evening sessions. We select one evening session for investigation, since the traffic data at other sessions gives identical results. The selected traffic data was collected from 04:41 p.m. to 09:56 p.m. on November 6, 2005. Considering the behaviors of users in the session, three data sets at the beginning, middle and end of the session are selected for detailed analysis. These three data sets were collected from 04:41 p.m. to 05:11 p.m., from 06:06 p.m. to 06:36 p.m. and from 09:26 p.m. to 09:56 p.m.

3.1 Characteristics Analysis Method

To analyze the impact of different types of frame traffic on the aggregated frame traffic, we first calculate the overall characteristic parameters in these three data sets, and then recalculate the corresponding parameters after removing a specific traffic type. The impact of this specified frame traffic on the aggregated frame traffic can be evaluated by identifying and analyzing the differences in the calculated characteristic parameters. In order to minimize the measurement deviation, the differences of characteristic parameters are calculated at three time scales, i.e. 0.01, 0.05 and 0.1 second time scales. The mean values will be used to indicate the impacts of the specified frame traffic type on the overall traffic characteristics. Particularly, the Hurst and α characteristic parameters are calculated for evaluating the impact of specified frame traffic type on the self-similarity and burstiness of the aggregated frame traffic. The impact parameters are calculated by the following formulas:

$$\Delta_{Hurst,\, frame\_type} = \frac{1}{3} \sum_{time\_scale} (X_{time\_scale,\, frame\_type} - X_{time\_scale, aggregated\_frame}); \quad (3)$$

$$\Delta_{\alpha,\, frame\_type} = \frac{1}{3} \sum_{time\_scale} (Y_{time\_scale,\, frame\_type} - Y_{time\_scale, aggregated\_frame}). \quad (4)$$

$\Delta_{Hurst,\, frame\_type}$ is defined as the self-similarity impact parameter. A positive value of the self-similarity impact parameter means that the specified frame traffic weakens the self-similarity of aggregated frame traffic, and vice versa. $\Delta_{\alpha,\, frame\_type}$ is defined as the burstiness impact parameter. A positive value of the burstiness impact parameter means that the specified frame traffic strengthens the burstiness of aggregated frame traffic, and vice versa. The subscript parameter of $frame\_type$ denotes the type of frame traffic, which includes the management frame, the control frame and the data frame. X and Y are variable values measured from the specified frame traffic at different time scales, and the subscript parameter of $time\_scale$ denotes the time scale used for measuring the frame traffic, taking values from the set $\{0.01, 0.05, 0.1\}$ in these experiments. The subscript parameter of $aggregated\_frame$ means that the variable value is measured from the total frame traffic.

3.2 Impact of Different Types Frames

Firstly, we investigate the impact of the management frame traffic on the aggregated frame traffic. This impact effect is calculated by the self-similarity and burstiness impact parameters formed in (3) and (4) in different session periods and is illustrated in **Fig. 1**. From the solid line in **Fig. 1**, we see the self-similarity impact parameter is positive in the beginning and end session periods, but it closes zero in the middle session period. From the dashed line in **Fig. 1**, the burstiness impact parameter is negative in the beginning and end session periods, but it is positive in the middle session period. According to these measurement figures, we can obtain the following observation result,

Observation 1: the management frame traffic weakens the self-similarity and burstiness of the aggregated frame traffic in the beginning and end session periods, but it strengthens or maintains these two parameters in the middle session period.

Secondly, the impact of the control frame traffic on the aggregated frame traffic is investigated by the corresponding self-similarity and burstiness impact parameters at the beginning, middle and end of the selected session, as illustrated in **Fig. 2**. In the **Fig. 2**, we see the self-similarity impact parameter is negative in the beginning and end session periods, but it is positive in the middle session period. Moreover, the burstiness impact parameter is positive in the beginning and end session periods, but it is negative in the middle session period in the **Fig. 2**.

Observation 2: the control frame traffic strengthens the self-similarity and burstiness of the aggregated frame traffic in the beginning and end session periods, but it weakens these two parameters in the middle session period.

Thirdly, the impacts of data frame traffic on the aggregated frame traffic are investigated by the corresponding self-similarity and burstiness impact parameters at the beginning, middle and end of the selected session, as illustrated in **Fig. 3**. It is clear that the self-similarity impact parameters are always negative in all session periods and the burstiness impact parameters are always positive in all session periods.

Observation 3: the data frame traffic always strengthens the self-similarity and burstiness of the aggregated frame traffic in the all session periods.

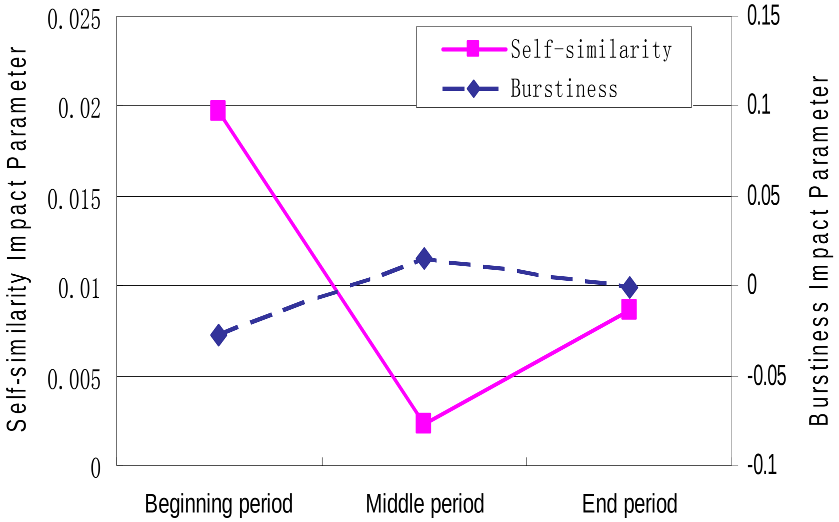

Fig. 1. Impact parameters of the management frame traffic at different session periods.

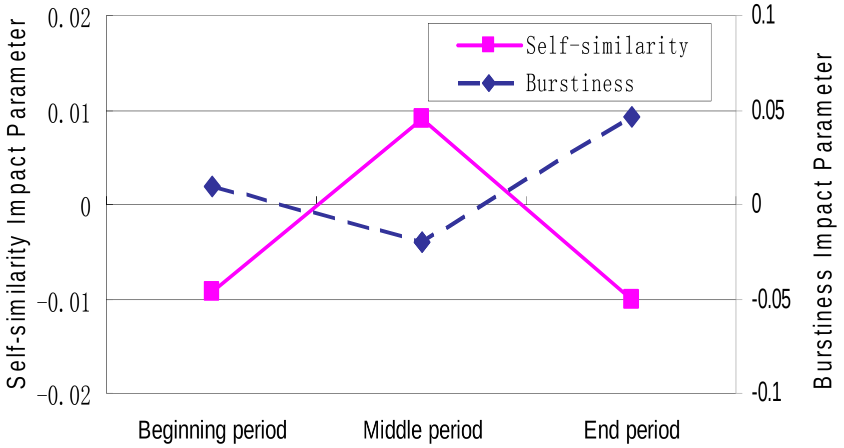

Fig. 2. Impact parameters of the control frame traffic at different session periods.

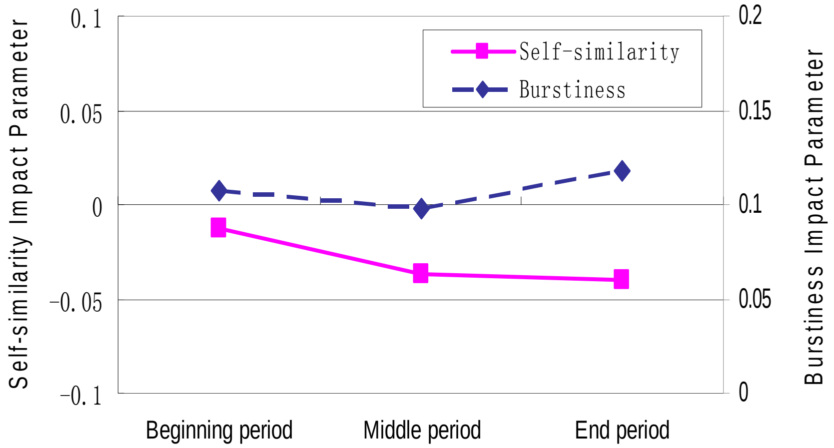

Fig. 3. Parameters of the data frame traffic at different session periods.

3.3 Characteristic Analysis

According to the measurement results of impact parameters from different types of frame traffic, the data frame traffic always strengthen the self-similarity and burstiness of the aggregated frame traffic in all session periods. However, the management frame traffic and control frame traffic have various impacts on the aggregated frame traffic in different session periods. To investigate the potential reasons of these measurement results, we calculated the mean frame size and the proportion changes of the specified frame traffic in different session periods. The corresponding results are illustrated in **Fig. 4** and **Fig. 5**.

Fig. 4 demonstrates that the proportion of the management frame traffic is obviously large in the beginning and end session periods, but it is small in the middle session period. More precisely, the proportion of the management frame traffic accounts for 38.2% in the beginning session period and 22.2% in the end session period, while the proportions of the management frame traffic accounts for 5.8% in the middle session period.

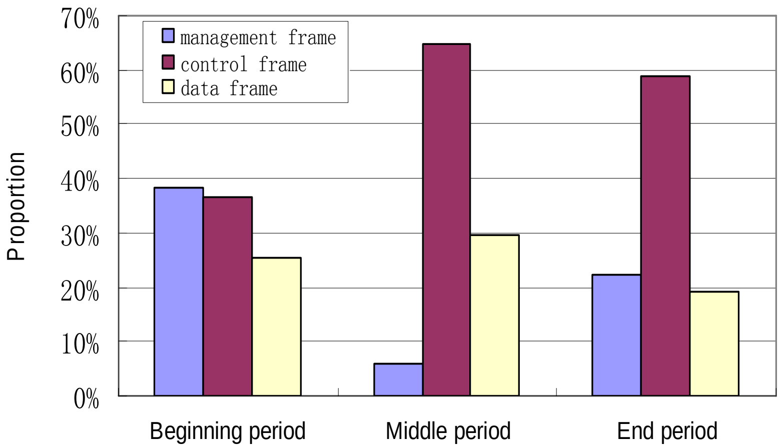

Fig. 4. Proportions of different types of the frame traffic at different session periods.

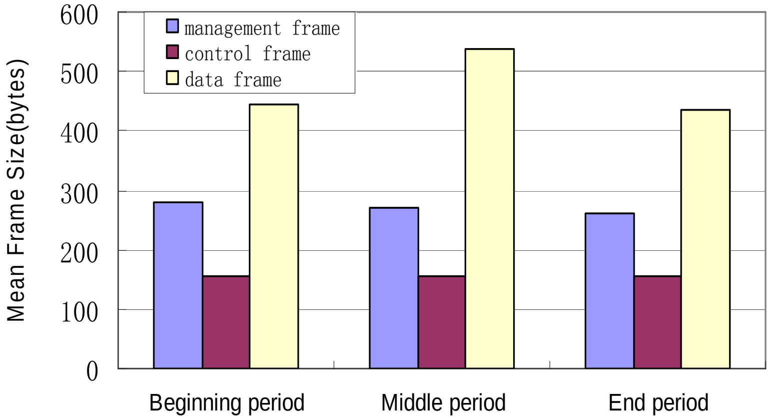

Fig. 5. Mean sizes of different types of frames.

The proportion of management frames exceeds the proportion of data frames at the beginning and end session periods, which is determined by the combined user behavior at the conference. After analyzing the characteristics of management frames in different session periods, we find that there exists a mass of beacon frames, association/disassociation frames, authentication/deauthentication frames at the beginning and end session periods. This phenomenon is due to the fact that many users try to join/leave a BSS and connect/disconnect with Internet at the beginning and end session periods. On the contrary, in the middle session periods, most users have already joined a BSS and connected with the Internet. So, the number of management frames, such as beacon frames, association/disassociation frames, authentication/deauthentication frames, used to identify the BSS and connect with Internet in the middle session periods is obviously less than that at the beginning and end session periods. Therefore, we observe that the proportion of management frames is large at the beginning and end session periods, but small in the middle session period.

For the proportion of the control frame traffic, the **Fig. 4** illustrates that it is the largest in the middle session period, but it is small in the beginning and end session periods. Because of lacking of further information in the control frames from the collection data, we just presume that this result is caused by the user behavior at the conference.

From **Fig. 5**, we can see that the mean frame sizes of management frames and control frames is obviously smaller than the mean frame size of data frames. The mean frame size of management frame in the all session periods is approximately 270 bytes, and the mean frame size of control frame in the all session periods is approximately 154 bytes. In the light of the Poisson statistical theory, the aggregation of large numbers of small size frames can smooth the burstiness and self-similarity of the total frame traffic. Thereby, based on the proportion changes of management and control frame traffic, the management frame traffic can weaken the self-similarity and burstiness of the aggregated frame traffic in the beginning and end session periods, and the control frame traffic can weaken the self-similarity and burstiness of the aggregated frame traffic in the middle session periods.

On the other hand, in the middle session period, the proportion of the data frame traffic achieves its the maximum proportion, i.e. 29.6%, but the mean frame size of the data frame traffic is the largest in all types of mean frame sizes, i.e. 537 bytes. Compared with the management frame traffic and control frame traffic in the beginning and end session periods, in the middle session period, the proportion of the data frame traffic is large than the proportion of the management frame traffic and less than the proportion of control frame traffic. Moreover, the mean frame size of the data frame traffic is the largest in the all frame types. As a result, the data frame traffic always strengthens the self-similarity and burstiness of total frame traffic. With reference to this analysis, an important analytical result has been emerged,

Analytical result 1: the impact of different types of frame traffic on the self-similarity and burstiness of the aggregated frame traffic is simultaneously related with their mean frame size and proportion in the total frame traffic.

Considering this analysis result just come from one international conference, we collected another conference frame traffic traces from the 62th Internet Engineering Task Force (IETF) conference for measuring and analyzing. The analysis results from the IETF frame traffic express the same analysis result, so it could be seen that this analysis result general exist in the international conference frame traffic traces [30].

Compared with the previous work [11][12] that only analyzes the aggregated frame traffic characteristics, our analytical results provide an insight for designing more efficient optimization mechanisms. For instance, the burstiness of the aggregated frame traffic can be weakened if a new MAC mechanism can reduce the data frame size when their proportion is small in the total frame traffic. So that the conflict of access medium could be decreased, and then the error frames and the retransmission frames could also be reduced.

4. Network Model

To analyze the performance of new mechanism and simulation experiments, a system network model is built in **Fig. 6**. Because above research focuses on the frame traffic which is realized in the MAC layer, the new improved mechanism should also be designed in the MAC layer. Moreover, the main function of MAC layer in the IEEE 802.11 protocol is to guarantee the reliable transmission in one jump range. Therefore, the system network model is implemented in one BSS as **Fig. 6**.

In the **Fig. 6**, there are N nodes and an AP, and the nodes communicate each other by the AP switching. To verify the performance of the new mechanism, we use the IEEE 802.11b protocols as the baseline protocol in our simulation, by only adding the new mechanism in the MAC layer of all nodes. Most parameter values of simulation experiments are configured based on the IEEE 802.11b standards, and part of specified parameters values in these simulation experiments is illustrated in the **Table 2**.

According to the measurement results in reference [12], more then 28% data frames is made up of the retransmission frames, and these retransmission frames account for more than 46% data transmission time. With reference to the IEEE 802.11 protocols, all these retransmission frames is caused by the error frames which is mainly due to the burstiness frame traffic. Thereby, how to regulate the burstiness of frame traffic is a great challenge in the traffic control mechanism of 802.11 networks.

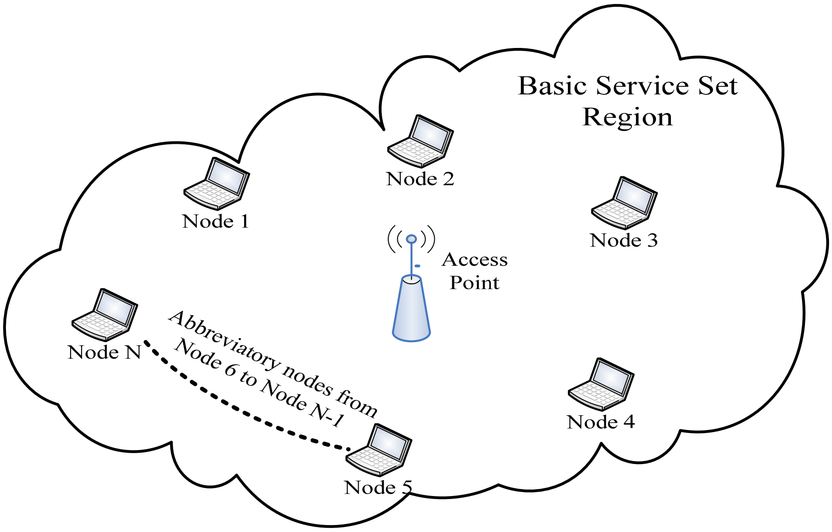

Fig. 6. System network model in the simulation experiments

Table 2. Parameters configuration in the simulation experiment

Parameter	**Value**
Interval of beacon frame	0.1 second
AFSO algorithm measurement period	6 seconds
Arrival distribution of frames in every node	Parote distribution
Distribution of initial data frame size	Uniform distribution in the interval of [500, 2300] bits
Upper limit of data frame size	2346 bits
Lower limit of data frame size	320 bits
Transmission rate	5.5 Mbps, 11 Mbps

5. AFSO: Adaptative Frame Size Optimization Mechanism

Considering the frame traffic measurement results in section 3, it is implied that the burstiness (or self-similarity) of the aggregated frame traffic can be regulated if the size and proportion of date frame traffic are correspondingly adjusted. In general, it is very difficulty to directly change the proportion of data frames in the total frame traffic or the size of management and control frames fixed by the IEEE 802.11 standards. However, we can adjust the size of data frame by adopting a new frame size optimization mechanism in the MAC layer. From the measurement results of different types frame traffic, it is implied that the change of mean frame size and proportion of data frame traffic can adjust the self-similarity (or corresponding burstiness) of the aggregated frame traffic, so we propose a new AFSO mechanism to achieve this aim.

The new AFSO mechanism includes two parts：

- In the first part, the proportion of data frame traffic in one period should be calculated and recorded, and then the new transmitted data frame size can be configured based on the proportion of data frame traffic in the past period. Before describing the AFSO mechanism, let us explain a few variables as follows. *data_frame_size* is the current data frame size. *upper_limit_size* is the upper limit of data frame size, which is configured by the size of maximum frame unit in the IEEE 802.11b standards. *lower_frame_size* is the lower limit of data frame size, which is configured by the size of maximum management or control frame unit in the IEEE 802.11b standards. After one period, the AP node will calculate the proportion of data frame traffic in the past observation period. Because all frames in the air can be divided into three frame types (i.e. data frame, management frame and control frame), and the proportions of three type frames are approximately equal to 33% when the frame traffic is measured in a stable period, such as in the middle period. Therefore, we assume the proportion threshold of data frames is 33% in this new mechanism. When the proportion value of data frame traffic is large than 33%, it implies the data frame traffic will strength the burstiness on the total frame traffic. In this case, the average size of all frames should be improved by increasing the transmitted data frame size, and then the burstiness caused by the data frame traffic can be correspondingly suppressed. So that, the data frame size should be increased until it reaches the upper limit of data frame size. Based on this idea, the increment of data frame size is designed as following,

$$data\_frame\_size = \begin{cases} upper\_limit\_size\ , \\ \text{when } data\_frame\_size \geq upper\_limit\_size - 100\ ; \\ data\_frame\_size + 100\ , \\ \text{otherwise}\ ; \end{cases} \tag{5a}$$

When the proportion value of data frame traffic is less than or equal to 33%, the inverse decision is educed and the decrement of data frame size is designed as following,

$$data\_frame\_size = \begin{cases} lower\_limit\_size\ , \\ \text{when } data\_frame\_size \leq lower\_frame\_size + 100\ ; \\ data\_frame\_size - 100\ , \\ \text{otherwise}\ ; \end{cases} \tag{5b}$$

We have analyzed the simulation results in section 6, the performance of the new algorithm can achieve the most optimal value when adjustment unit of data frame size is equal to 100 bits in (5a) and (5b). Thereby, the adjustment unit of data frame size is assumed 100 bits in this paper.

- In the second part, the adjustment information of data frame size should be distributed to all nodes in the BSS, and then all nodes including the AP node in the BSS will adjust the new transmitted data frame size in next period. According to the IEEE 802.11 protocol, the AP node periodically sends the beacon frame carrying the BSS information to all nodes in the BSS. Therefore, we add three bits in the end of standard beacon frame format.

The added first bit is identified as F, and the added second and third bits are identified as FT. The adjustment information carried by F and FT is presented in **Table 3**.

Table 3. The added beacon frame body

Identifier	Information	Notes
F	0	AFSO mechanism has not been used.
F	1	AFSO mechanism has been used.
FT	00	Data frame size = data frame size – 100.

FT	01	Data frame size = lower limit of frame size.
FT	10	Data frame size = data frame size + 100.
FT	11	Data frame size = upper limit of frame size.

Based on the new AFSO mechanism, the corresponding realization algorithm is listed below in **Fig. 7**.

```
Input: the number of data frames and the total frames in the past observation period;
Output: the adjusting information of data frame size in one observation period;
Initialization
The AFSO algorithm is triggered after an observation period,
Begin

    Calculating Proportion and Frame Size in the AP
    1.  Update the number of data frames and the total frames in the past observation period;
    2.  Calculate the proportion of data frame in the total frames in the past observation period;
    3.  Calculate the new data frame size based on (5a) or (5b);
    4.  Record the adjusting information of data frame size in the temporary variables.

    Distributing Adjustment Information in the BSS
    1.  Identify the AFSO mechanism is used in the 'F' position of beacon frame;
    2.  Fill the adjust information of data frame in the 'FT' position of beacon frame;
    3.  Transmit the beacon frame to all nodes in the BSS.

    Adjusting Frame Size
    1.  All nodes in the BSS configure the new transmitted data frame size, and encapsulate the new
        data frames based on the new size values.

End
```

Fig. 7. Algorithm for AFSO

The complexity of the new algorithm is $O(n)$, where n is the number of total frames in one observation period.

6. Simulation Results

We first analyze the performances of AFSO algorithm in the 5.5 and 11 Mbps transmission speeds. The simulation results on the successful data delivery ratio and throughput rate compared with these two algorithms, AFSO algorithm versus standard IEEE 802.11b algorithm, are shown in the **Fig. 8-10**. The definition of successful data delivery ratio is as follow

$$\text{successful data delivery ratio}=\frac{\text{bits number of correct data frames in the receiver}}{\text{bits number of transmission data frames in the sender}}. \quad (6)$$

The definition of throughput rate is as follow

$$\text{throughput rate}=\frac{\text{IEEE 802.11b throughput}}{\text{AFSO throughput}}. \quad (7)$$

In the **Fig. 8** and **Fig. 9**, compared with standard IEEE 802.11b algorithm in 5.5 and 11 Mbps transmission speeds, the successful data delivery ratio used AFSO algorithm is improved. However, in the **Fig. 10**, with the increasing of the number of communication links, the throughput rates in 5.5 and 11 Mbps transmission speeds are not obviously improved. The mean values of throughput rates in 5.5 and 11Mbps transmission speeds are 0.996 and 1.005, and the variance values of throughput rates in 5.5 and 11Mbps transmission speeds are 0.011 and 0.008. Therefore, it could be said that the throughput used AFSO algorithm is approximately with the throughput used IEEE 802.11b algorithm, but the successful data delivery ratio is improved. It means the total WLAN transmission efficiency used AFSO mechanism, compared with IEEE 802.11b algorithm, is improved.

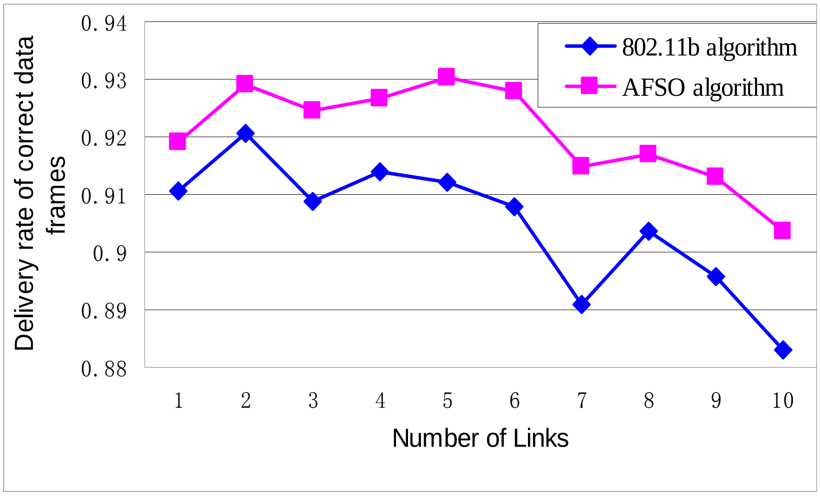

Fig. 8. Successful data delivery ratio between the AFSO algorithm and IEEE 802.11b algorithm in 5.5 Mbps transmission speed.

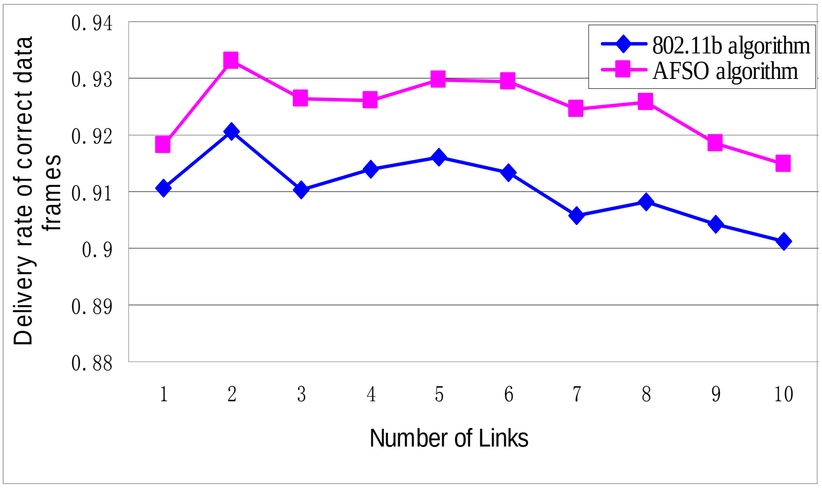

Fig. 9. Successful data delivery ratio between the AFSO algorithm and IEEE 802.11b algorithm in 11 Mbps transmission speed.

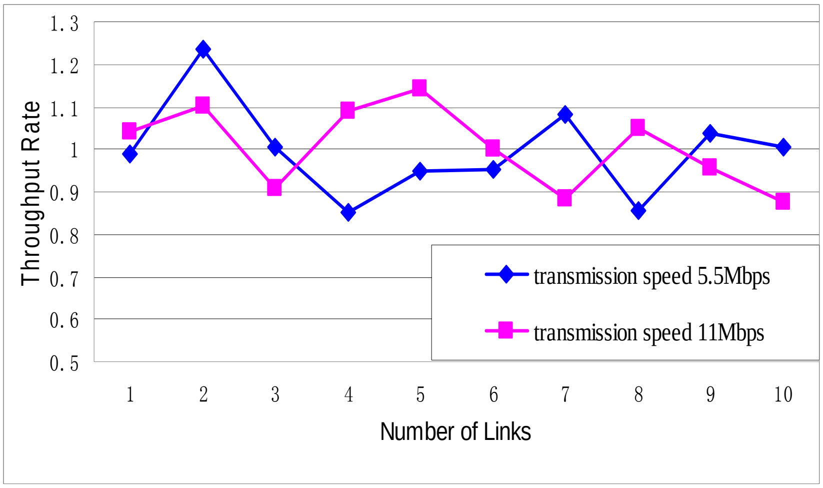

Fig. 10. Throughput rate in 5.5 and 11 Mbps transmission speed.

Based on the idea of AFSO mechanism, the size of data frames is adjusted with the proportion of data frame traffic in total frame traffic, and then the burstiness (or self-similarity) of total frame traffic can be maintained in a stable level. Furthermore, the retransmission frames and error frames caused by the intense burstiness of frame traffic can be reduced. Therefore, the successful data delivery ratio is improved in the simulation experiments when the total throughput is not obviously increased. Hence, the AFSO mechanism can not obviously improve the total throughput in the WLAN, but this mechanism can improve the transmission efficiency in the WLANs by advancing the successful data delivery ratio.

7. Conclusions

In this paper, we investigate the impact of different frame types on the burstiness and self-similarity characteristics of the aggregated frame traffic, and then find that the burstiness of frame traffic simultaneously depends on the mean frame size and different frame type proportion. Furthermore, according to the relationship between the burstiness of frame traffic and the mean frame size and proportion, an AFSO mechanism is proposed to improve the transmission efficiency by reducing the error frames in the 802.11 wireless networks. These new results increase the knowledge of the inherent relationships among different types frame traffic, and provide an approach for regulating the burstiness of frame traffic in the 802.11 wireless networks. In practice, there are also other factors that affect the regulation of frame traffic in the 802.11 wireless networks, such as the relationship among different types of frame traffic, the transmission rate of frame traffic, link asymmetry and fairness among heterogeneous traffic, etc. Our findings show that the frame size and proportion of different frame traffic can influence the burstiness or self-similarity of aggregated frame traffic, therefore how to balance the relationship among the different types of frame traffic to further regulate the characteristics of total frame traffic is our important future work. In addition, we will also consider heterogeneous traffic types like web oriented traffic flows in 802.11 wireless networks for performance evaluation, instead of using solely FTP traffic.

References

[1] S. Chatziperis, P. Koutsakis, and M. Paterakis, “A new call admission control mechanism for multimedia traffic over next-generation wireless cellular networks,” *IEEE Transaction on Mobile Computing*, vol. 7, no. 1, pp. 95-112, Jan. 2008.

[2] P. Min, K. young, and V. Rodoplu, “Core capacity region of portable wireless networks,” *IEEE Transaction on Wireless Communications*, vol. 6, no. 11, pp. 3897-3901, Nov. 2007.

[3] O. Tickoo and B. Sikdar, “On the impact of IEEE 802.11 MAC on traffic characteristics,” *IEEE Journal on Selection Areas Communications*, vol. 21, no. 2, pp. 189-203, Feb. 2003.

[4] Z. Lu, Y. Yang, Y. H. Song, and T. Owens, “Characterization of Real GPRS Traffic with Analytical Tools,” in *Proc. of IEE Conf. on 3G and Beyond*, pp. 56-61, 2005.

[5] X-H. Ge, G-X. Zhu, and Y-T. Zhu, “On the Testing for Alpha-Stable Distributions of Network Traffic,” *Computer Communication (Elsevier Science)*, vol. 5, no. 27, pp. 447-457, May 2004.

[6] Y-X. Cao, K-C. Leung, and V.O.K. Li, “Bandwidth-Guaranteed Fair Scheduling with Effective Excess Bandwidth Allocation for Wireless Networks,” *IEEE Transaction on Wireless Communications*, vol. 7, no. 6, pp. 2094-2105, June 2008.

[7] J. Yu and A.P. Petropulu, “Study of the effect of the wireless gateway on incoming self-similar traffic,” *IEEE Transaction on Signal Processing*, vol. 54, no. 10, pp. 3741-3758, Oct. 2006.

[8] F. Chinchilla, M. Lindsey, and M. Papadopouli, “Analysis of wireless information locality and association patterns in a campus,” in *Proc. of IEEE Conf. on Computer Communications*, pp. 906-917, 2004.

[9] T.B. Reddy, B.S. Manoj, and R. Rao, “On the Accuracy of Sampling Schemes for Wireless Network Characterization,” in *Proc. of IEEE Conf. on Wireless Communications and Networking*, pp. 3314-3319, 2008.

[10] Q. Liang, “Ad Hoc Wireless Network Traffic — Self-Similarity and Forecasting,” *IEEE Communication Letters*, vol. 6, no. 7, pp. 297-299, June 2002.

[11] IEEE 802.11 WG. Part 11: wireless LAN MAC and physical layer specifications. IEEE Standard 802.11, 1999.

[12] M. Rodrig, C. Reis, R. Mahajan, D. Wetherall, and J. Zahorjan, “Measurement-based characterization of 802.11 in a hotspot setting,” in *Proc. of ACM Conf. Special Interest Group on Data Communication*, pp. 5-10, 2005.

[13] D. Aguayo, J. Bicket, S. Biswas, G. Judd, and R. Morris, “Link-level measurements from an 802.11b mesh network,” *ACM SIGCOMM Computer Communication Review*, vol. 34, no. 4, pp. 121-132, Oct. 2004.

[14] P. A. Jardosh, K. N. Ramachandran, K. C. Almeroth, and E.M. Belding-Royer, “Understanding Link-Layer Behavior in Highly Congested IEEE 802.11b Wireless Networks,” in *Proc. of ACM Conf. Special Interest Group on Data Communication*, pp. 11-16, 2005.

[15] P. A. Jardosh, K. N. Ramachandran, K. C. Almeroth, and E.M. Belding-Royer, “Understanding Congestion in IEEE 802.11b Wireless Networks,” in *Proc. of ACM Conf. Special Interest Group on Data Communication*, pp. 20-25, 2005.

[16] X-H. Ge and Y. Yang, “Characteristics of Frame Traffic in 802.11 Wireless Networks,” in *Proc. IEEE Conf. on Mobile Ad-hoc and Sensor Networks*, pp. 295-298, 2008.

[17] J. L. Sobrinho and A.S. Krishnakumar, “Real-time traffic over the IEEE 802.11 medium access control layer”, *Bell Labs Technical Journal*, vol. 1, pp. 172-187, 1996.

[18] L. Bononi, M. Conti, and E. Gregori, “Design and performance evaluation of an asymptotically optimal backoff algorithm for IEEE 802.11 wireless LANs”, in *Proc. of IEEE Conf. on System Sciences*, pp. 10-13, 2000.

[19] N. Vaidya, S. Gupta, and P. Bahl, “Distributed fair scheduling in a wireless LAN”, *IEEE Transaction on Mobile Computing*, vol. 4, no. 6, pp. 616-629, Nov.-Dec. 2005.

[20] D. Gu, and J. Zhang, “A new measurement-based admission control method for IEEE802.11 wireless local area networks”, in *Proc. of IEEE Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 2009-2013, 2003.

[21] D. Ko, S. Han, and H.J. Cha, "A traffic control system for IEEE 802.11 networks based on available bandwidth estimation", *Wireless Communications and Mobile Computing*, vol. 8, no. 4, pp. 407-419, May 2008.
[22] Y. X. Lin and V. W.S. Wong, "An admission control algorithm for multi-hop 802.11e-based WLANs", *Computer Communications*, vol. 31, no. 14, pp. 3610-3520, Sept. 2008.
[23] F. Didi, M. Feham, H. Labiod and G. Pujolle, "Dynamic admission control algorithm for WLANs 802.11", in *Proc. of IEEE Conf. on Telecommunications*, pp. 1-6, 2008.
[24] R. Zhu, J.Q. Wang, and M.D. Ma, "Intelligent MAC model for traffic scheduling in IEEE 802.11e wireless LANs", *Applied Mathematics and Computation*, vol. 205, no. 1, pp. 109-122, Nov. 2008.
[25] http://crawdad.cs.dartmouth.edu/.
[26] W.E. Leland, M.S. Taqqu, W. Willinger, and D.V. Wilson, "On the self-similar nature of Ethernet traffic," *IEEE/ACM Transaction on Networking*, vol. 2, no. 1, pp. 1-15, Feb. 1994.
[27] O.D. Jones, and Y. Shen, "Estimating the Hurst index of a self-similar process via the crossing tree," *IEEE Signal Processing Letters*, vol. 11, no. 4, pp. 416-419, Apr. 2004.
[28] T. Konstantopoulos and V. Anantharam, "Optimal flow control schemes that regulate the burstiness of traffic," *IEEE/ACM Transaction on Networking*, vol. 3, no. 4, pp. 423-432, Aug. 1995.
[29] F. Hong, R. Liu, and Y. Bai, "Performance evaluation of the burstiness impact with a realistic IP structure model," in *Proc. of IEEE Conf. on Computer Science and Information Technology*, pp. 345-349, 2009.
[30] K. Zhang, X-H. Ge, C. Liu, X. Lin, "Analysis of frame traffic characteristics in IEEE 802.11 networks," in *Proc. of IEEE Conf. on China Communications*, pp. 1-5, 2009.

Xiaohu Ge is currently an Associate Professor with the Department of Electronics and Information Engineering at Huazhong University of Science and Technology (HUST), China. He received his Ph.D degree in Communication and Information Engineering from HUST in 2003. He has worked at HUST from Dec. 2005. Prior to that, he worked as an assistant researcher at Ajou University (Korean) and Politecnico Di Torino (Italy) from Jan. 2004 to Dec. 2005. His research interests are in the area of mobile communication, traffic modeling in wireless networks, as well as interference modeling in wireless communications. Dr.Ge serves as an Editor for the international journals KSII Transactions on Internet and Information Systems. He is a Member of the IEEE.

Cheng-Xiang Wang received the BSc and MEng degrees in Communication and Information Systems from Shandong University, China, in 1997 and 2000, respectively, and the PhD degree in Wireless Communications from Aalborg University, Denmark, in 2004. He has been with Heriot-Watt University, Edinburgh, UK since 2005, first as a Lecturer and then as a Reader in 2009. He is also an Honorary Fellow of the University of Edinburgh, an Adjunct Professor of Guilin University of Electronic Technology and Huazhong University of Science & Technology, and a Guest Researcher of Xidian University. He was a Research Fellow at the University of Agder, Grimstad, Norway, from 2001-2005, a Visiting Researcher at Siemens AG, Munich, Germany, in 2004, and a Research Assistant at Technical University of Hamburg-Harburg, Germany, from 2000-2001. His current research interests include wireless channel modelling and simulation, cognitive radio networks, vehicular communication networks, green radio communications, cooperative (relay) communications, cross-layer design, MIMO, and (beyond) 4G wireless communications. He has published 1 book chapter and over 120 papers in refereed journals and conference proceedings. He is the leading Principal Investigator of the UK-China Science Bridges Project: R&D on (B)4G Wireless Mobile Communications, awarded by Research Councils UK. He is currently serving as an Editor for 3 international journals. He also served as an Editor for IEEE Transactions on Wireless Communications from 2007 to 2009. He is the leading Guest Editor for IEEE Journal on Selected Areas in Communications, Special Issue on Vehicular Communications and Networks. He served or is serving as a TPC member, TPC Chair, and General Chair for about 60 international conferences. He is listed in “Dictionary of International Biography 2008 and 2009”, “Who's Who in the World 2008 and 2009”, "Great Minds of the 21st Century 2009", and "2009 Man of the Year". He is a Senior Member of the IEEE, a member of the IET, and a Fellow of the HEA.

Yang Yang received the BEng and MEng degrees in Radio Engineering from Southeast University, Nanjing, P. R. China, in 1996 and 1999, respectively; and the Ph.D degree in Information Engineering from The Chinese University of Hong Kong in 2002. He is currently the Assistant Director and Vice CTO at Shanghai Research Center for Wireless Communications (WiCO), Chinese Academy of Sciences. Prior to that, he served the Department of Electronic and Electrical Engineering at University College London (UCL), United Kingdom, as a Lecturer and a Senior Lecturer from 2005 to 2010, the Department of Electronic and Computer Engineering at Brunel University, United Kingdom, as a Lecturer from 2003 to 2005, and the Department of Information Engineering at The Chinese University of Hong Kong as an Assistant Professor from 2002 to 2003. He has published more than 70 refereed journal and conference papers in the areas of wireless communications, covering wireless ad hoc and mesh networks, cross-layer performance evaluation and optimization, radio resource management, medium access control (MAC) protocols, and routing algorithms in wireless sensor networks. He is on the editorial board of IEEE Communications Magazine, International Journal of Sensor Networks, Journal of Wireless Communications and Mobile Computing (Wiley), etc. and was a guest editor of the Special Issue on “Network Coverage and Routing Schemes for Wireless Sensor Networks” for Computer Communications (Elsevier) and a guest editor of the Special Issue on “Wireless Mesh Networks: Applications, Architectures and Protocols” for IEEE Network Magazine. Since 2003, he has been actively involved in the organisation of more than 30 international conferences, such as Technical Co-Chair of IEEE Broadnets’08, Co-Chair of Wireless Access Track at IEEE VTC’08 (Spring), Co-Chair of Wireless Sensor Networks Symposium at ACM IWCMC (06-09), Publicity Chair for Bodynets’07, and Session Chair and TPC member for several IEEE ICC and IEEE Globecom conferences.

Lei Shu is a currently Specially Assigned Research Fellow in Department of Multimedia Engineering, Graduate School of Information Science and Technology, Osaka University, Japan, and was a Research Scientist in the Digital Enterprise Research Institute (DERI), at the National University of Ireland, Galway (NUIG). He received the B.Sc. degree in Computer Science from South Central University for Nationalities, China, 2002, and the M.Sc. degree in Computer Engineering from Kyung Hee University, Korea, 2005, and the PhD degree in Digital Enterprise Research Institute, NUIG, in 2010. He has published over 80 papers in related conferences, journals, and books. He has been awarded the MASS 2009 IEEE TCs Travel Grant and the Outstanding Leadership Award of EUC 2009 as Publicity Chair. He has served as editor of a number of international journals, e.g., IET Communications, KSII Transactions on Internet and Information Systems (TIIS), Journal of Internet Technology; and guest co-editor of: Springer Telecommunications System, Ad Hoc & Sensor Wireless Networks, Wiley Security and Communication Networks, Journal of Communications. He has served as more than 25 various Co-Chair for international conferences/workshops, e.g., PICom 2009/2010, CIT 2010, IWCMC 2011, Chinacom 2010, BodyNets 2010, EUC 2009, EmbeddedCom 2009; TPC members of more than 100 conferences. He has served as reviewer of more than 50 journals, including, IEEE Network Magazine, IEEE Transaction on Wireless Communications, IEEE Journal of Selected Areas in Communications, etc. His research interests include semantic sensor networks, wireless sensor network, context aware and sensor network middleware. He is a member of IEEE.

Chuang Liu is currently a graduate student in the department of Electronics and information engineering at Huazhong University of Science and Technology, China. He received his bachelor's degree in Information Engineering from South China University of Technology, in 2008. His research interests are in IEEE 802.11 wireless local area networks.

Lin Xiang received his bachelor's degree in electronic and information engineering from Huazhong University of Science and Technology (HUST) in June, 2009. He is currently working toward his master's degree in communication and information systems at HUST. His present research direction is traffic modeling in wireless networks.