A MANET System Supporting TDMA and CSMA on One Commercial Network Card

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Abstract—Mobile Ad-hoc network (MANET) has great potential applications for these cases where there is no infrastructure or infrastructure is damaged. However, there are no mature products publicly available so far on markets. The current standardized technology either does not support Ad hoc network or does not provide enough bandwidth to support video transmission. Further more, those technologies are all based on Carrier Sense Multiple Access (CSMA) channel access control, which will greatly degrade network performance due to serious access conflicts in a large scale network. Meanwhile CSMA can not guarantee in its mechanism that commander messages are always transmitted out in-time enough. A new type of MANET communication terminal is presented in this paper, aiming to solve the problems. Its main characteristics are to support both CSMA and Time Division Multiple Access (TDMA) on a commercial WiFi network card hardware and to be able to switch between CSMA and TDMA adaptively according to conflict rate of channel access. With this approach, a MANET with balanced performance for small- and large-scale network is achieved.

Index Term**—**Ad-hoc network, MANET, emergency communication, CSMA, TDMA

I. INTRODUCTION

Mobile Ad-hoc network (MANET) is proposed primarily to establish a stable network in the infrastructure-free or infrastructure-destroyed scenarios [1], [2]. With the advantages of no central nodes, self-organizing, multi-hop routing and dynamic topology, MANET can be used in a variety of applications, such as military communications and civil emergency communications [3], [4]. However, there are no mature products publicly available so far on markets.

For future MANET, it is important to provide enough bandwidth to support video transmission and large scale network. Such demands bring about the challenges for the implementation of MANET communication devices. Currently IEEE 802.15.4, i.e. the air interface of ZigBee, is the only one standardized technology that supports Ad-hoc network in terms of multi-hop communication, but its data transmission rate is hardly to meet the requirement of video transmission. IEEE 802.11, the air interface of WiFi, has much higher transmission speed than ZigBee, however it does not support non-infrastructure network and its derived protocol WiFi-direct works well only for point-to-point communication.

On the other hand, those popular wireless technologies are based on Carrier Sense Multiple Access (CSMA) channel access control, which will greatly degrade network performance due to serious access conflicts in a large scale network. When the number of nodes increases from 5 to 50, the network throughput declines by 30% and the probability of collision increases by 1.7 times with CSMA [5], [6]. Meanwhile unlike TDMA, CSMA can not guarantee in principle that commanders of mission team have their messages be transmitted out in-time enough. To the best of our knowledge, there are no off-the-shelf TDMA wireless network cards available on market so far.

Some organizations and companies, e.g. Internet Engineering Task Force (IETF) and Lucent Technologies (LU), are committed to propose Ad-hoc protocol standards [7], [8]. A few manufactures of military are developing MANET terminals. For example, Rockwell Collins Inc. developed such devices for Tactical Targeting Network Technology (TTNT) that support communications among UAVs, aircrafts, ships and ground vehicles [9]-[11]. Harris Inc. launched into market the hand-held MANET voice radio products Falcon III and Thales Synaps-H V/UFH [12], [13]. However, these systems are not suitable for civil applications, and the devices can not provide enough bandwidth to support well video transmission.

Aiming to solve the above problems, this paper presents a new type of MANET communication terminal that supports both CSMA and TDMA on one commercial WiFi network card hardware and is able to switch between CSMA and TDMA adaptively according to the conflict rate of channel access. The whole system implementation is based on our previous work [14]. With this approach, a MANET with balanced performance for small and large network is achieved.

The rest of the paper is organized as follows. Section II introduces the system architecture of the MANET system, including hardware design and software design. Section III describes the implementation of TDMA channel access in the MANET system, as well as the adaptive mode switching mechanism. Section IV shows the results

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Manuscript received August 2, 2019; revised January 4, 2020

This work is supported by Heifei University of Technology (JZ2015QSJH0536).

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doi:10.12720/jcm.15.2.148-156

and performance of the test. Section V makes a short summary of this paper.

II. System Architecture

The MANET system designed in this paper is mainly used for military communications and civil emergency communications. Therefore, the system must support basic communication functions such as text, images, voice, video and files. In addition, we also designed special functionality to strengthen the urgent command transmission and situational awareness. The main technical parameters of the MANET system are summarized in Table I.

TABLE I: MAIN TECHNICAL SPECIFICATION

Parameter	Value
Carrier frequency	2.4GHz/IEEE802.11g
Channel access control	TDMA or CSMA
Range of one hop	Maximum 1Km
Networking	Ad-hoc
Network capacity	256 nodes
Video compression	H.264
Encryption at App layer	3DES, MD5
Text-to-speech	ShoushuoTTS by shoushuo studio
Power supply	5V/2A, DC

A. *Hardware Architecture*

In order to get a balance among hardware performance, cost and popularity, we chose the Exynos4412 with 2GB RAM and 16GB flash memory as core board. The designed peripherals and interfaces are shown in Fig. 1.

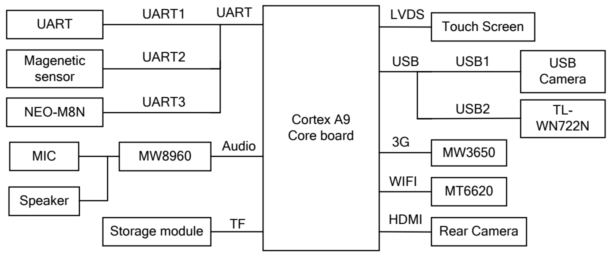


Fig. 1. Hardware architecture of MANET system.

The system provides two types of network interface: local area network through WiFi and wide area network through mobile 3G. Two WiFi modules are configured on the board, one is used as TDMA/CSMA Ad hoc network interface that is based on our own MAC protocol, the other is stand WiFi interface.

Two cameras are connected to the main board through HDMI port and USB port respectively. Voice data are compressed and decompressed by the chip MW8960. GPS module NEO-M8N and its PPS (pulse per second) signal are connected to provide geographical position information and accurate timing service for the system. Magnetic sensor module provides direction information for the situation-awareness software module.

B. *Software Architecture*

The software architecture of the MANET system is shown in Fig. 2. The software design is divided into four parts, i.e., user authentication, common settings, general communication and special communication.

The user authentication module is used for login authentication and account maintenance. The common settings are mainly used to set the channel access mode and edit one-click commands, and it can also provide modification of user nicknames, selection of working languages, etc. General communication module mainly supports the function of voice, text, video, etc. Special communication is primarily used to accomplish the three functions that we designed for emergency communications, i.e., situation map display, one-click command and text-to-speech.

Location information and direction information are integrated on the situation map display, which enables the commander to clearly grasp the current position of his soldiers and mark appropriate attack points. Furthermore, the situation map provides soldiers with a simple direction navigation, which allows them to reach the destination point in the shortest distance.

The commander can edit important commands before performing the task. These commands can be sent by one-click command functions. This greatly reduces the editing time for sending commands.

Text-to-speech can play the commander's one-click command, so that the soldiers will not miss important instructions when they are not looking at the screen.

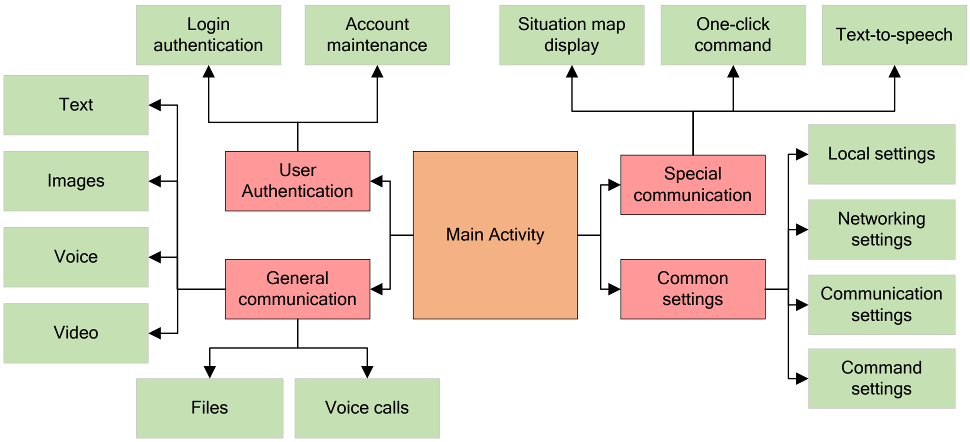


Fig. 2. Software architecture of MANET System.

III. TDMA Channel Access and Adaptive Mode Switching

A low delay and jitter, stable throughput channel access is very important for MANET systems. As far as we know, the current network card on the market is widely based on CSMA channel access. Nevertheless, CSMA cannot provide stable channel access for the MANET system, because as the number of nodes increases, packet collisions and delays increase, and then the network throughput drops dramatically [15]. When the CSMA channel is saturated, the channel access delay increases as the number of nodes increases [16]. This is due to the competition mechanism of the CSMA protocol.

The nondeterministic communication behavior of CSMA makes 802.11 unsuitable for mission- and safety-critical applications with high-reliability requirements, at least in its standard form [17]. In contrast, TDMA channel access assigns each node with independent time slots for transmission. This provides stable throughput and low delay and jitter channel access for MANET systems. At the same time, the TDMA channel access mode can provide a fairer channel access for each node, which can prevent a few nodes from occupying channels all the time.

However, as far as we know, there is currently no off-the-shelf TDMA network card available for MANET system. After a series of investigations, we decide to modify the commercial network card TL-722N to make it support TDMA channel access.

In this section, we will describe the key processes for implementing TDMA channel access, including commercial network card modification, time slot design, clock synchronization and packet-accurate control. Furthermore, considering the balance between channel utilization and the delay and jitter, an adaptive mode switching mechanism is also proposed to provide optimal channel access for the MANET system.

A. Commercial Network Card Modification

The hardware platform for implementing TDMA is the AR9271 wireless network card (TL-WN722N). The card complies with the 802.11g protocol and implements channel access through CSMA. We mainly modify its MAC layer to support TDMA channel access. Prior to this, we need to prevent the original CSMA mechanism from interfering with the implementation of TDMA.

After understanding the mechanism of CSMA [18], [19], we propose a method to disable the CSMA mechanism. The method mainly includes the following five steps: disabling carrier sensing function, resetting all 802.11 data packet frame intervals, disabling back off function, disabling RTS/CTS signaling, and disabling the chip waiting for ACK. After these modifications, the packets inserted into the hardware transmission queue can be sent to the physical channel immediately.

Through research, we found that the AR9271 chip series network card can run the open source ath9k-htc firmware to perform the CSMA disabling stratgegy. The relevant parameters in the network card are controlled by the memory mapped register. In order to achieve the above-mentioned CSMA disabling strategy, we set the values of the registers as shown in Table II.

TABLE II: REGISTER SETTINGS FOR DISABLING CSMA

Register	Description	Value
AR_DIAG_SW	Control carrier sense and back off	CLEAR | IGNORE | IDLE
AR_D_GBL_IFS_SIFS	$SIFS$	0
AR_D_GBL_IFS_SLOT	$SLOT$	0
AR_QTXDP	$CW_{\min}$、$CW_{\max}$ and $AIFSN$	0
AR_Q_TXE	Contains a pointer to the transmission queue.	-

AR_DIAG_SW is used to control carrier sense and back off. Carrier sense and back off are disabled when its value is set to CLEAR | IGNORE | IDLE. AR_D_GBL_IFS_SIFS is used to control the time duration from the successful reception of the data to the sending of the acknowledgement, denoted as $SIFS$. AR_D_GBL_IFS_SLOT is used to control the slot duration $SLOT$. AR_QTXDP is associated with a priority-dependent duration $AIFSN$, and the minimum (maximum) window length $CW_{\min}$ ($CW_{\max}$) for each queue. All of the above three registers are related to the RTS/CTS, so we set their values to 0. AR_Q_TXE points to the starting address of the transmission queue. After these settings, packet transmission will not be interfered by the original CAMA mechanism.

B. Time Slot Design

Time Division Multiple Access (STDMA) meets the real-time requirements of dynamic changes in topology and the large number of devices in mobile ad hoc networks [20]. In addition to real-time communication, our TDMA-based MAC also needs to support video.

The core of TDMA-based MAC design lies in two points. One is to design a time slot that meets real-time requirements and supports video. The other is clock synchronization and precise control of packet delivery. This part mainly describes the design of time slots. Unless otherwise specified, the time variables used in this chapter are in microseconds.

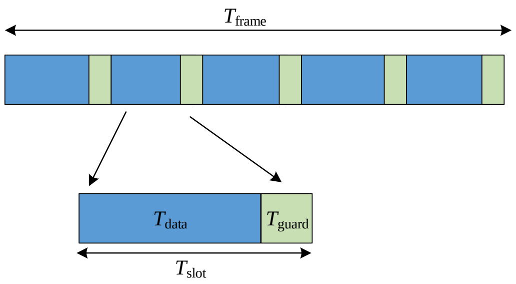


Fig. 3. Frame and slot structure.

The structure of the time slots and frames is shown in Fig. 3. The time duration of each frame is designed as a fixed value T_{frame}. Each frame is divided into N_f time slots, each with T_{slot} time duration. The relationship between them is expressed as

$$N_f = T_{\text{frame}} / T_{\text{slot}} \tag{1}$$

Each time slot consists of a data packet transmission time duration T_{data} and a guard time duration T_{guard}. The relationship between them is expressed as

$$T_{\text{slot}} = T_{\text{data}} + T_{\text{guard}} \tag{2}$$

TDMA-based MAC adopts dynamic reserved time slots and updates reservation information every frame. In order to ensure that the time slot reservation can be flexibly updated, T_{frame} cannot be too large. At the same time, in order to accommodate sufficient number of nodes within one frame, T_{frame} cannot be too small. After comprehensive consideration, we determine the frame length T_{frame} to be 1999816μs.

In the design of time slots, we mainly consider supporting real-time voice and video. In view of this, the channel resources allocated to each node must fulfill the throughput and delay and jitter requirements of the voice and video. First, for real-time voice, we refer to the G.723.1 standard [21], whose transmission requirement is 24 bytes / 30ms. For real-time video transmission, we refer to the most widely-used H.264 standard [22]. We select a normal quality video (352 × 288, 30 frames/sec) for the MANET system. To meet real-time video and voice requirements, the system's slot interval need be less than 30ms, each slot must transmit more than 24 bytes, and the maximum packet transmission rate must be greater than 768Kbps.

In the design, the packet size for each slot (L_{slot}) is set to 540 bytes. Meanwhile, guard time duration is set to 18μs and data time duration is set to 310μs, i.e.,

$$T_{\text{slot}} = T_{\text{data}} + T_{\text{guard}} = 328\mu s\,. \tag{3}$$

Since the system adopts slot reservation mechanism, we design a reporting rate to limit the number of slots available to each node within one frame. The maximum reporting rate $R_{\max}$ is set to 425, and the minimum reporting rate $R_{\min}$ is set to 66.

When transmitting with the maximum reporting rate, each node can get a transmission rate of $(R_{\max}/2)\times L_{\text{slot}} = 1024$ Kbps. Meanwhile, the time duration of each time slot is $T_{\text{frame}}/R_{\max} = 4.21$ ms. Hence, the time slots we designed can meet the requirements of real-time voice and video applications.

C. Clock Synchronization and Packet Precision Control

Clock synchronization is important for implementing TDMA channel access. The 18μs guard duration is comprised of three parts, expressed as

$$T_{\text{guard}} = T_{\text{re-trans-air}} + T_{\text{clock-drift}} + T_{\text{sch-drift}} \tag{4}$$

$T_{\text{re-trans-air}}$ (5μs) is the data transmission delay in the air; $T_{\text{sch-drift}}$ (5μs) is the High Resolution Timer (HRT) maximum timeout error, and $T_{\text{clock-drift}}$ (8μs) is the clock drift of the MANET system. This means that the MANET system must ensure that the clock synchronization error is less than 8μs.

In order to make the MANET system obtain clock synchronization that meets the time slot design requirements in various usage environments, we design two modules for clock synchronization. One is the internal clock synchronization module, which does not require GPS signal support. The other is a clock synchronization module based on PPS seconds pulse, which requires GPS signal support.

The internal clock synchronization module is mainly divided into two steps: rough clock synchronization and precious clock synchronization. We define the first node in each cluster to be the “master”, and the node that starts later is the “slave”. In the rough clock synchronization phase, slave node selects the latest master’s beacon, and uses the receiving timestamp of the beacon as the rough relative slot boundary. Precious clock synchronization occurs in the first frame, and its specific process is shown in Fig. 4.

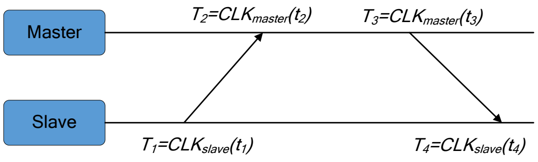


Fig. 4. Precise clock synchronization.

The main idea of precious clock synchronization is to calculate the clock difference between the slave and the master, and then the slave performs clock correction based on the clock difference. First, the slave node sends a clock request in which its timestamp T_1 is carried. After receiving the clock request, the master node uses its own timestamp T_2 to calculate the relative time difference $T_{\text{offset-ms}} = T_2 - T_1$. Then the master sends a clock synchronization response at time T_3 with its own timestamp. After receiving the clock response, the slave node uses its own timestamp T_4 to calculate the relative time difference $T_{\text{ms-offset}} = T_4 - T_3$. Finally, after the data exchange, the slave node can calculate the clock deviation T_{offset} between slave node and the master node, shown as

$$T_{\text{offset}} = (T_{\text{offset-sm}} - T_{\text{offset-ms}})/2 \tag{5}$$

The PPS second pulse synchronization requires the support of the Ublox module and it can provide more accurate and stable clock synchronization accuracy. It needs to accept two messages, including the NMEA0813 message with full UTC time and the PPS seconds pulse signal. The rising edge of PPS second pulse is used to mark the full second time of the UTC time, which can be used to reduce the error between the MANET system clock and UTC time. First, the system obtains the current UTC time by parsing the NMEA0813 message, which is equivalent to the rough clock synchronization. Then, the MANET system employs the PPS seconds pulse to align its clock with the UTC time, which is equivalent to precious clock synchronization.

As shown in Fig. 5, t_{ini} is the time extracted from the NMEA0813 message; t_{offset} is the boundary difference between t_{ini} and the rising edge of the second pulse; t_{clock} is the time after clock synchronization. We let the GPIO port work in interrupt mode and let the rising edge trigger work in the interrupt registration function. Then, we place the clock synchronization function in the interrupt handler. Each time the PPS second pulse arrives, the interrupt handler can be triggered to complete the alignment of the MANET system clock with UTC seconds.

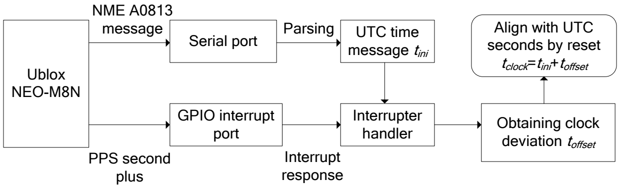


Fig. 5. PPS second pulse clock synchronization implementation.

When there is a GPS signal, the system synchronizes the clock through the PPS seconds pulse. PPS second pulse synchronization is more accurate and it can reduce the consumption of channel resources. When there is no GPS signal, the system completes the synchronization through the internal clock synchronization module. In this way, we design reliable clock synchronization to support TDMA channel access.

After precious clock synchronization, we design the precise control of packet transmission mechanism. We use a high-resolution timer (HRT) to precisely schedule the transmission of packets. The main process is shown in Fig. 6.

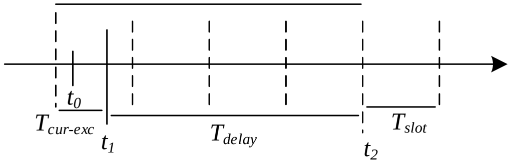


Fig. 6. Precisely control packet transmission with HRT.

At time t_0, the MAC receives the data request of the transport layer. Then, the MAC searches the slot table to get the next arranged slot index S_{trig}. At time t_1, the MAC calculates the current slot index S_{cur} and the slot overflow time $T_{\mathrm{cur\text{-}exc}}$ of the current moment after adding the packet header to the packet. Finally, the waiting time T_{delay} of the HRT is calculated as:

$$T_{\mathrm{delay}} = (S_{\mathrm{trig}} - S_{\mathrm{cur}}) \times T_{\mathrm{slot}} - T_{\mathrm{cur\text{-}exc}} \tag{6}$$

After calculating the waiting time T_{delay}, the HRT will start to work. At time t_2, the HRT triggers the push of the packet to the physical layer immediately. Due to the disabling of CSMA, the physical layer can send the packet directly without waiting for the channel to be idle.

D. Adaptive Mode Switching Mechanism

The MANET system designed in this paper supports TDMA channel access. Therefore, it guarantees real-time communication when the channel is saturated. However, the maximum reporting rate R_{max} limits the maximum number of slots that can be used by one node, which would result in a low channel utilization of TDMA when the channel is idle.

According to the time slot design, when there is only one node in the network for packet transmission, its channel utilization η_{uti_one} is expressed as

$$\eta_{\mathrm{uti\_one}} = (R_{\mathrm{max}} \times T_{\mathrm{slot}}) / T_{\mathrm{frame}} = 7.79\% \tag{7}$$

In order to obtain better channel access, adaptive hybrid MAC is a good way to balance small- and large-scale networks. There are some researches based on adaptive hybrid MAC. Z-MAC is a hybrid MAC protocol based on network topology, which is difficult to apply to self-organizing networks with frequent network topology changes. MCCA is a hybrid protocol for TDMA-CSMA with a central wireless network that cannot be used in a non-central ad hoc network [23]. This paper proposes an adaptive MAC switching mechanism based on channel conditions.

The adaptive switching process is implemented by the following process. When TDMA is required, the MANET system will load the ath9k_htc firmware with CSMA disabled and load the TDMA based MAC. When CSMA is required, the MANET system needs to unload the TDMA-based MAC and load the firmware that supports CSMA. The channel access mode is automatically selected to balanced performance for small- and large-scale networks. This adaptive mode switching mechanism is depicted in Fig. 7.

In Fig. 7, the channel access mode is denoted as *mode*, CS and TD represent the CSMA and TDMA mode, respectively. *sw* is the mode switching flag, where Y stands for the decision of switching, and N stands for the decision of staying at the original mode. *stM* is a manned flag, where EN means enabling mode switching function and DIS means disabling mode switching function. $T_{\text{pk-dey}}$ is the maximum packet delay, and *nf* is the number of packets retransmitted within one minute. r_{video} represents channel throughput when performing video transmission. η_{tdma} stands for the current channel utilization, and t_{status} is the time duration from system performance becoming unsatisfactory till the decision of mode switching.

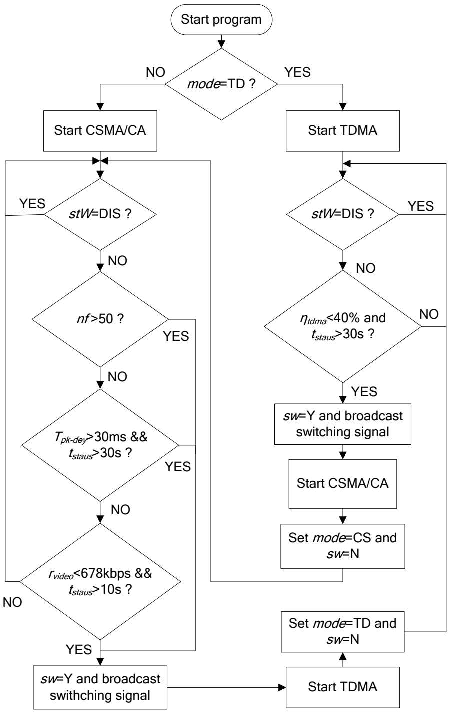


Fig. 7. Adaptive mode switching mechanism.

The system first selects the corresponding channel access mode according to the value of *mode*. Then, the system checks the value of *stM* . If the mode switching function is disabled (*stM* =DIS), the system enters the monitoring state for the value of *stM* . Once the mode switching function is enabled (*stM* =EN), the process will be divided into two cases.

If the current mode is CSMA, there are three conditions for triggering mode switching. The first trigger condition is the number of packets that cannot be successfully transmitted after 7 consecutive retransmissions within one minute exceeds 50. The second trigger condition is that the packet transmission delay is greater than 30ms, which affects the real-time voice call function. The last trigger condition is that the video throughput is lower than 768Kbps, which affects the video call function. Once one of the above three conditions happens, *sw* is set to Y, and the system broadcasts a switching flag to inform all the nodes in the network. Finally, the system completes the switching to TDMA mode.

If the current mode is TDMA and the current channel utilization is less than 40%, the system broadcasts a switching flag to inform all the nodes in the network. After that, the system completes the switching to CSMA mode.

IV. TESTSING PERFORMANCE

To evaluate the performance of the MANET system, we conduct some experiments, including clock synchronization accuracy test, single-node full-load test and multi-node fixed-flow test.

A. *Clock Synchronization Accuracy Test*

Time synchronization is very significant for TDMA channel access. If the clock synchronization error is larger than $T_{\text{clock-drift}}$, slot collisions will occur. Therefore, we conduct an experiment to test the synchronization accuracy of the MANET system. We use 10 systems to form a network and select one as the master node. When the clock synchronization is completed, the master node sends packets with a serial number and a timestamp to the remaining nine slave nodes every 200ms. After receiving the packet, each slave records the packet serial number and timestamp and then calculates its synchronization time $t^{[s]}$, expressed as

$$t^{[s]} = t_{\text{ori}}^{[s]} - T_{\text{trans}} \tag{8}$$

where s is the serial number of the packet; T_{trans} is the transmission delay of the packet; $t_{\text{ori}}^{[s]}$ is the timestamp which is marked when the packet is received. Finally, we count the average clock synchronization error for each node. We conduct an hour of experiment and collect 90000 synchronization errors, the results of which are shown in Table III.

TABLE III: CLOCK SYNCHRONIZATION ACCURACY TEST

Notion	Value
Average synchronization error	7.8 μs
Maximum synchronization error	88 μs
Minimum synchronization error	7 μs
Synchronization error standard deviation	0.5 μs

Experiment results demonstrate that the average clock synchronization error is 7.8μs. In the test, we also find that 99% of the errors are less than 8μs. In this regard, we can conclude that the clock synchronization accuracy satisfies the requirements of the service.

B. *Single-Node Full-Load Test*

In order to compare the performance of CSMA with that of TDMA when the channel is relatively idle, we design single-node full-load test. This experiment respectively tests the TCP and UDP throughput of a single node. The results are averaged over a total of 30 tests, with each test lasting for one minute. The experiment results are shown in Table IV.

TABLE IV: SINGLE-NODE FULL-LOAD THROUGHPUT TEST

Mode	TCP Transmission		UDP Transmission	
	Average Rate	Average Jitter	Average Rate	Average Jitter
TDMA	676.7Kbps	1.25ms	1004.5Kbps	0.84ms
CSMA	17.6Mbps	3.81 ms	18.8Mbps	1.78ms

From Table IV, we can see that when a single node sends packets, the rate of TDMA is lower than CSMA. This is due to the limitation of $R_{\max}$, which makes TDMA not fully use channel resources. When accessing through CSMA, the system can maximize the utilization of channel resources.

It can be concluded that CSMA channel access can provide higher channel utilization and guarantee lower jitter when the channel is not crowded.

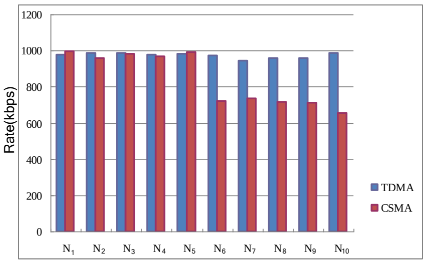
C. *Multi-Node Fixed-Flow Test*

In order to compare the performance of TDMA with that of CSMA in a relatively crowded channel, we design a multi-node fixed-flow experiment. In this experiment, 10 MANET systems are placed in a single hop range. They are started in series, and form into 5 transmission pairs. Every node sends packets to its paired mate at the rate of 1000Kbps. The experiment tests the average throughput and average jitter of 10 MANET systems for both TCP and UDP transmissions. The results are averaged over a total of 30 tests, with each test lasting for one minute, and the results are shown in Table V.

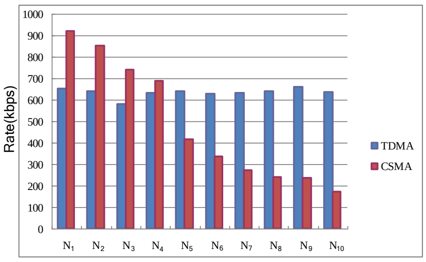
TABLE V: MULTI-NODE FIXED-FLOW THROUGHPUT TEST

Mode	TCP Transmission		UDP Transmission	
	Average Rate	Average Jitter	Average Rate	Average Jitter
TDMA	634.5Kbps	6.82ms	972.1Kbps	3.91ms
CSMA	508.2Kbps	32.45ms	843.4Kbps	24.87ms

Table V shows that no matter for TCP or UDP transmission, the average throughput when accessing through TDMA is higher than through CSMA. Meanwhile, the average jitter of TDMA is much lower than that of CSMA. This indicates that when the channel is congested, the collision probability of accessing through CSMA will increase, thereby resulting in reduced throughput and increased jitter.



(a) UDP transmission throughput

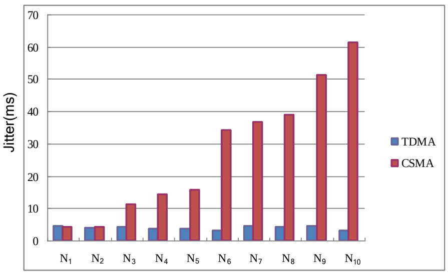


(b) TCP transmission throughput

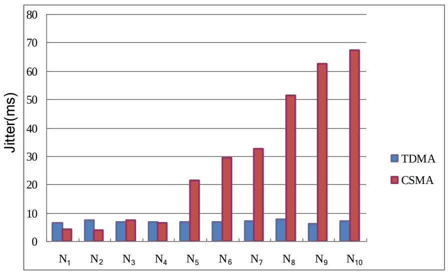
Fig. 8. Comparison of throughput for TDMA and CSMA.

The transmission throughput and jitter of each node are respectively shown in Fig. 8 and Fig. 9, where node i is denoted as N_i $(i=\{1,2,\ldots 10\})$. From Fig. 8 and Fig. 9, we can see that the throughput and jitter of each node for TDMA are more stable than that for CSMA. That is to say, when accessing through TDMA, the system can obtain a fairer channel resource. When accessing through CSMA, the amount of channel resources allocated to each node is related to its starting time. MANET systems that access channels earlier can obtain more channel resources, resulting in higher throughput and lower jitter. On the contrary, the MANET systems that access the channel later can only obtain less channel resources, resulting in lower throughput and larger jitter.

From the above experimental results, we can see that CSMA is suitable for small networks, while TDMA can provide real-time communication for large networks. With the adaptive channel mode switching mechanism, our MANET can have a balanced performance for small- and large-scale networks.



(a) UDP transmission jitter



(b) TCP transmission jitter

Fig. 9. Comparison of jitter for TDMA and CSMA.

V. CONCLUSIONS

In this paper, we present a new type MANET system that can support TDMA and CSMA on one commercial network card. The hardware and software architecture of the system are introduced. The approach of implementing TDMA on one commercial network card, adaptive channel access mode of TDMA and CSMA, the issue of time synchronization and the test results are detailed. The proposed MANET system has a balanced performance for small- and large-scale networks.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Zhizhong Ding and Momiao Zhou conducted the research. Ke Cheng implemented the harwware and conducted system tests. Yinling Fu implemented the application layer software. Zechen Lin, Tian Jiang and Xuewen Guo implemented the low layer software. Ke Cheng wrote the manuscript. Zhizhong Ding and Momiao Zhou revised the paper. All authors had approved the final version.

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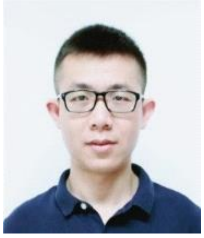

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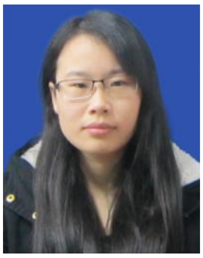

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