OPPORTUNISTIC RADIO FOR MULTI-CHANNEL USAGE IN WLAN AD HOC NETWORKS

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ABSTRACT

This paper proposes an implementation of opportunistic radio for multi-channel usage in the IEEE 802.11-based ad hoc networks. Terminals in mobile ad hoc networks have to organize and manage the network since there is no base station to act as the central control unit. For this reason, terminals in current WLAN ad hoc networks employ the approach of "listen before talk" which means that once the network is set up, only one channel can be observed and used throughout. A great deal of work has been done to develop methods to allow the usage of multiple channels since there are three non-overlapping channels for 802.11b/g and twelve non-overlapping channels for 802.11a. However, these approaches mostly focus on the modification of MAC protocol to support the multi-channel usage. In this work, the proposed method employs a physical spectrum sensing, which is one of the opportunistic radio functionalities, to determine resource availability and make decision accordingly. The simulation results are provided to illustrate the potential benefits of the proposed approach in terms of system performance in comparison with the current WLAN ad hoc networks as well as with the multi-channel MAC approaches.

1. INTRODUCTION

In Mobile Ad Hoc Networks (MANETs), there are several supporting standards available such as Bluetooth and the IEEE 802.11 standards family. The IEEE 802.11 standard is considered here as an ad hoc infrastructure due to the reason that the supporting technologies are capable of meeting the current trend and are able to offer more flexibility in the exploitation of the white space in order to improve system performance. The technology such as Orthogonal Frequency-Division Multiplexing (OFDM), which is employed in both 802.11a and 802.11g, is also one of the techniques highly focused in the area of cognitive radio.

The key aspect that differentiates MANETs from other wireless networks is the fact that MANETs are infrastructureless networks which means that the networks are self-organized and formed solely by mobile terminals without any base stations or access points. Therefore, the system performance is optimized through the terminals coordination. Without base stations to perform the central management, each terminal has to act as both a network host for transmitting and receiving data and as a router forwarding packets to the destination node often located outside the transmission range of the source node. With such challenges, current bandwidth utilisation has been compromised since the MAC protocol specified in the IEEE 802.11 is considered as a single-channel MAC protocol. In the infrastructure network, the access point decides on channel allocation for each terminal. Without the central authority to perform channel management, IEEE 802.11-based ad hoc networks operate on a single channel. This creates problems such as rapid performance degradation due to increased traffic load, while the rest of the spectrum could be left unused. To improve the spectrum usage and service performance, multi-channel utilization is an attractive solution and it has been widely researched. The benefit of using multiple channels is clearly the higher system throughput since at least non-overlapping channels can be used simultaneously.

Existing research in multi-channel MAC protocol provides a rather different approach toward the exploitation of multiple channels from the one proposed in this work. However, they are aiming for the use of more than one non-overlapping channel within the same ISM band. Most of the current approaches for multi-channel utilization focus on the modification of MAC protocol to allow the spatial awareness of channel availability. The reason is that there is no need to have additional hardware to periodically scan each channel. A number of these proposed protocols show promising benefits. However, they focus on the status-based method using MAC protocol modifications rather than the measurement-based method, which is part of the opportunistic radio sensing functionality proposed here. By taking physical sensing into account, opportunistic radios offer spatial awareness on a real-time basis. The radio concept used in this work is termed as Opportunistic Radio (OR), which is a narrower definition of Cognitive Radio (CR) where the environment knowledge is restricted to spectrum awareness. The cooperative sensing is employed in this work to avoid hidden terminal problem, which could happen when sensing in particular channels cannot be done while OR terminal operates in a different channel.

The paper presents the development of the WLAN ad hoc network simulator integrated with OR capability to perform cooperative sensing and spectrum allocation. System level platform is simulated and discussed. The basic models are presented along with the ad hoc scenario description. System performance evaluation is described in terms of impact on throughput and delay characteristics.

In the next section, issues in IEEE 802.11-based ad hoc networks are discussed along with related works. Section 3 describes the work proposed here for opportunistic radio in multi-channel ad hoc networks in detail. In section 4, the system level simulator developed to study the performance brought by the proposed method is. Next, test scenarios and simulation results for the basic case and the test results in comparison with existing works are then presented in section 5. Lastly, the paper draws a conclusion in section 6.

2. ISSUE IN IEEE 802.11 BASED AD HOC NETWORKS AND RELATED WORK

The drawbacks of a current single-channel MAC protocol have been discussed along with the current research trend to solve the problems. In this section, several existing approaches are categorized and conceptually described. In the next section, the OR approach will be brought into the topic with discussion and comparison with existing proposed methods. The approaches are categorized into the following types.

2.1. Dedicated control channel approach

In this approach, one channel is dedicated as a control channel and used for the exchange of RTS/CTS, where the channel selection process is also included. The other channels are used for data transmission.

Most proposals are classified as multiple transceiver protocols. They employ two or more half-duplex transceivers to offer a rather straightforward method with less complexity. One transceiver is tuned to the control channel, therefore the RTS/CTS exchanges with channel selection can be monitored at all times. The other transceiver(s) is used for data transmission and can operate on different channels. Examples of approaches in this category includes DCA (Dynamic Channel Allocation) [1], DCA-PC (Dynamic Channel Allocation with Power Control) [2], GRID [3], and DPC (Dynamic Private Channel) [4]. The drawback for these approaches is due to the number of transceivers to be integrated into a mobile host, which could result in higher cost and increased battery usage. In the situation where the number of available channel is small, using one channel solely for controlling could affect the throughput performance. On the other hand, there is no need of any synchronization and the approach provides less complexity.

2.2. Split phase approach

In this category, only one transceiver is needed for each mobile host. The MMAC (Multi-channel MAC) [5] and MAP (Multi-Channel Access Protocol) [6] are example protocols for this approach. The main concept for this type of protocols is by dividing the time into the control phase and data transmission phase. During the control phase, all devices must tune to the control channel for the agreement on which channel to be used for the data transmission and then switch to such channel for data transmission phase. The benefit of this approach is obviously the use of single transceiver and all channels can be used for data transmission. However, synchronizations are needed. Another drawback is the wastage of channels during the control phase as all devices would vacate those channels and switch to operate on the control channel.

2.3. Channel hopping approach

This approach is also considered as a single transceiver approach. The concept of this approach is the synchronized channel hopping sequence for the control and data transmission phase. All channels are regarded as data channels. Node wishing to transmit data has to hop with the same sequence as the destination node. Once the control information is exchanged, they stay on the channel to complete date transmission. Examples of proposed methods are CHMA (Channel Hopping Multiple Access) [7] and SSCH (Slotted Seeded Channel Hopping) [8]. The drawback of this approach is similar to the split phase approach as the global time synchronization is needed here with rather high accuracy.

3. OPPORTUNISTIC RADIO IN MULTI-CHANNEL AD HOC NETWORK

As mentioned earlier, ongoing research largely focuses on this topic to facilitate the use of multiple channels within the unlicensed bands although the approaches are different from the one proposed in this investigation. The key potential benefit of implementing opportunistic radio comparing to previously discussed approaches is that the implementation is not restricted within a single standard or spectrum band giving more chance to search for available resources. Unlike the approaches previously discussed, this method allows users with opportunistic radio capabilities to determine spectrum availability in different bandwidth occupied by users with different networking standards This can be illustrated with a simple scenario of multihop ad hoc communications shown in Figure 1.

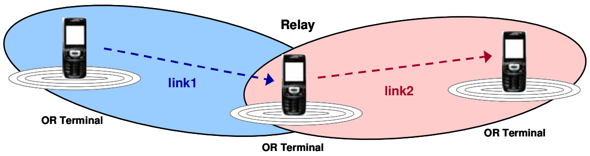

Figure 1: OR terminals in ad hoc network

The source node on the left is trying to send data to the destination node on the right through the relaying node. These three nodes are OR terminals embedded with OR sensing and band switching capabilities. Data packet from the source to destination is sent through link 1 and being forwarded by relaying node through link 2. In a legacy system, these two links need to operate on the same channel and implement the contention scheme to avoid interfering the others. However, the OR functionalities offer more flexibility to such scenario by allowing the two links to operation on different channels hence providing more chance of communication by searching for available channels within the transmission range of each link. Data could also be transmitted through both links simultaneously, in case of multi-transceivers terminal without interfering each other.

The potential benefits have been discussed above. However, this paper confines the study within a single ISM band (2.4 GHz band to be specific) in order to investigate the initial benefit of the approach keeping in line with the current usage prospective. The aim is also to compare the simulation results in terms of system performance against existing works, whose applications are solely restricted within the IEEE 802.11 standard family.

At the initial stage, opportunistic radio terminal is assumed to have single transceiver, which periodically performs spectrum sensing and OR signaling. The OR terminals in this case limit the sensing within the spatial domain i.e. within the same unlicensed band. Since the sensing process is done on a real time basis, hidden terminal is an important issue. According to [9], the spectrum sensing technique for cognitive radio can be classified as transmitter detection, cooperative detection, and interference-based detection. Most recent works have been focused on the transmitter detection because of the simplicity of the technique. However, this technique is done locally at the user leading to non cooperation. For the interference-based detection, secondary user relates the decision to the cumulative RF energy from multiple transmissions measured at the receiver. The secondary user will make use of the spectrum band if the set maximum interference limit is not exceeded by the aggregate RF energy level. These two techniques consider solely the spectrum sensing, which is done independently and locally at the secondary users. Without the central control to perform the spectrum allocation, cooperative sensing is more attractive for mobile ad hoc networks. The cooperative sensing is therefore implemented in this work. As mentioned above, hidden terminal problem is a very important issue in mobile ad hoc networks and the transmitter detection can not prevent this to happen. More detail on the system architecture and the development of the simulation platform are given in the next section.

4. SYSTEM LEVEL SIMULATOR

4.1. System Architecture

The implementation of opportunistic radio for multi-channel usage in WLAN ad hoc networks is investigated through a system level simulator. In Figure 2, the basic structure of the ad hoc network simulator is presented. On top of the legacy ad hoc system, the OR terminal is integrated with the spectrum sensing functionality and switching capability in the PHY layer as well as the channel allocation function in the MAC layer, which is done based on a simple decision-making process.

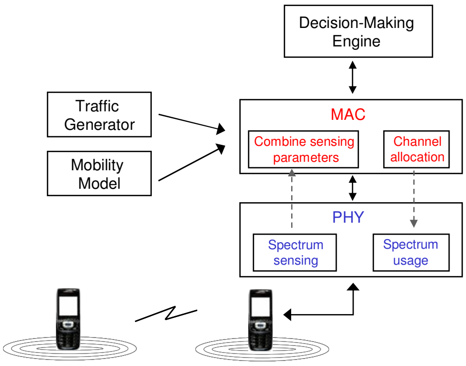

Figure 2: System architecture

4.2. Simulation Model

The ad hoc network simulator developed in this work is done using the MatLab simulator. The basic platform is validated against a simple test performed using the Network Simulator (ns-2). For the MAC layer, ns-2 provides the function to perform MAC protocol regarding the IEEE 802.11. However, the PHY layer functionality is rather simplified. From the basic simulator, extensions have been done to include the multi-channel usage capability to mobile nodes with a manual routing protocol. In addition, the opportunistic radio terminal is integrated with the sensing protocol as well as a simple channel allocation as part of the decision making process. Table 1 presents the topology for the simulator, which is used for the test scenarios discussed in section 5.

Table 1: Simulation parameters

Topography	1000m × 1500m
Transmission range	250m
Bandwidth	1Mbps
WLAN configurations	
SIFS	10μs
Slot Time	20μs
CWmin	31
CWmax	1023
Traffic type	Constant Bit Rate
Packet rate	
Test described in $5.1	4-200 packet/s
Test described in $5.2	1-1000 packet/s
Packet size	512 byte
Simulation time	
Test described in $5.1	300s
Test described in $5.2	80s

A traffic model is used to generate and control the activity within the tested scenarios. The most common traffic source used for ad hoc simulation is the CBR (Constant Bit Rate) source and it is also used in this work. The control parameter for the CBR traffic is the sending rate of packets per second. In other words, the inter-arrival time between consecutive packets is constant for the CBR traffic. The sending rate is dependent on the level of the traffic load to be tested.

The commonly used mobility model for ad hoc network simulation is called the Random Waypoint mobility model [10]. Two control parameters are the maximum speed and the pause time. The pause time is the period of time in second, when wireless node remains stationary. Node initially begins at the stationary stage for the pause time seconds. It then selects a random destination within the topography and move to the destination with the speed randomly selected between zero and the maximum value. Node moves to the destination with a constant speed following a direct path. Once reaches the destination, node stops for a pause time before choosing the next destination and speeds to continue the next movement.

Host mobility highly affects the system performance in mobile ad hoc networks, hence great deal of work has been done to propose efficient routing protocol to best manage the link performance. However, this work concentrates on evaluating the benefit brought by the intelligent and dynamic resource allocation hence initial scenarios involve solely static users at this stage.

The sensing model implemented in this work refers to the cooperative sensing protocol proposed for cognitive radio in [11]. At this stage only the high level is implemented although ongoing work is being developed for more detailed protocol. The sensing process is done periodically with a fix time interval of 200 ms. However, further studies should be done to investigate the effect of utilizing variable time frame. The sensing phase including node exchanging information at this stage is limited to 20ms given that the simulation focuses on small number of communication links and does not involve cluster configuration. Figure 3 depicts the high level sensing protocol proposed in [11], which is later adopted by [12].

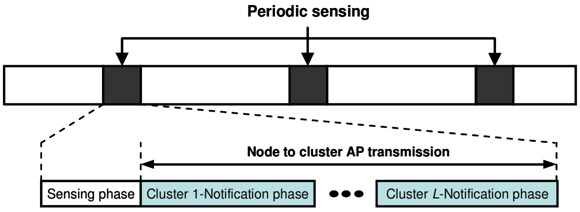

Figure 3: Spectrum Sensing Protocol [12]

5. AD HOC SCENARIOS AND RESULTS

Base on the simulation model described in the previous section, several test scenarios are implemented and the system performance is monitored in terms of aggregate throughput of the network and the average packet end-to-end delay. For the following test scenarios, all nodes are assumed to be located within the transmission ranges of other nodes throughout the simulation time.

5.1. Point-to-Point Scenario

Potential benefits of opportunistic channel allocation are firstly observed in an ideal case, where there are two communication links located within each others' ranges. Source node in each link in this test transmits stream of CBR traffic to the destination. Data rate is varied from 4 packet/s to 200 packet/s to allow the observation done on low to high traffic load situation. For each data rate, results are collected and averaged from ten runs. Figure 4 shows the simulation results for the aggregate throughput and average packet delay against traffic load in comparison between the system with one of the links being OR link and the system with both links as typical WLAN ad hoc network links.

It can be seen that even though the OR link needs to periodically complete spectrum sensing and OR signaling, the advantage in the channel allocation is monitored especially at the high traffic load when congestion starts to occur within a single channel situation. The reason is that the typical CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), provided by the IEEE 802.11 standard family, is designed to avoid collision by monitoring the channel availability by listening to the RTC/CTS exchange of others. Therefore, when the channel is busy, users have to wait until it becomes available before attempting to transmit. This results in long delay especially in congested situation. On the other hand, if one of the links has opportunistic radio capabilities, it can choose channel with less occupancy.

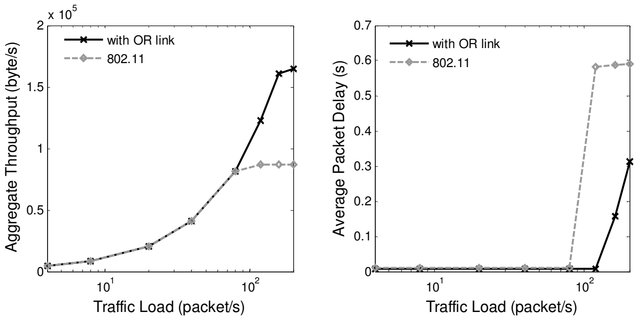

Figure 4: Simulation result for the aggregate throughput and average packet delay against traffic load

5.2. Comparison with Existing Multi-Channel MAC Approaches

In this test, the simulation scenario is set according to the reference works, whose proposals have been cited earlier as MMAC [5] and DCA [1]. The purpose is to observe the system performance in comparison with these well known multi-channel MAC approaches as well as with the current IEEE 802.11 standard.

5.2.1. Introduction to Existing Approaches

In [5], So and Vaidya proposed the MMAC protocol, which enable hosts to utilize multiple channels dynamically. The approach requests one transceiver per host and the key idea is to divide time into fixed-time intervals and allocate a small window at the start of each interval to dedicate traffic and negotiate channel to be used for data transmission during the interval. In [5], the performance of proposed protocol is evaluated using simulation also in comparison with the DCA protocol proposed by Wu et. al. [1]. DCA protocol assigns channel dynamically in an on-demand style. Each host is required to have two transceivers. One of the transceivers is used to listen to the control channel for the exchange of RTS/CTS packets, which is modified to included channel selection information. The other transceiver is dedicated to the data transmission.

5.2.2. Test Scenarios

In order to compare the system performance with previously described approaches, the test scenario is set according to the parameters used in the simulation model in [5]. Hence, assumptions are made to use three channels and the comparison is done against the test in section 6.1.1 on Wireless LAN in [5]. There are six nodes located within each other's transmission ranges. Hence, every source node can reach its destination in a single hop. Half of the nodes are sources and the other half are destinations forming three communication links. For basic simulation parameters, please refer to table 1.

5.2.3. Simulation Results

The system is evaluated in terms of aggregate throughput and average packet delay while the network load is varied. Packet arrival rate of CBR traffic for each flow is used to vary the traffic load and it is altered from 1 packet/s to 1000 packet/s.

Figure 5 shows the aggregated throughput against traffic load of the proposed OR implementation and the exsiting approaches as well as the current IEEE 802.11 standard. The plot for MMAC and DCA approach is referred to Figure 5(a) in [5]. In Figure 6, the average packet delay against traffic load is illustrated again for the proposed OR implementation approach in comparison with result from MMAC and DCA approach (referred to Figure 6(a) in [5]) also with the current IEEE 802.11 standard.

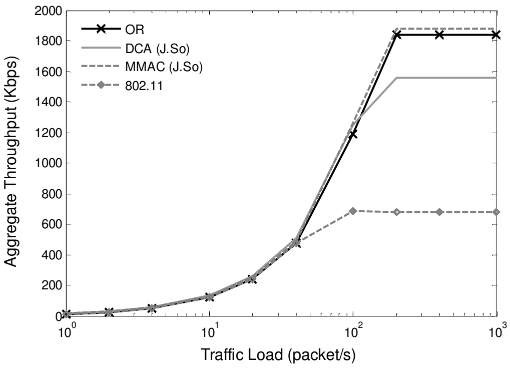

Figure 5: Aggregate through against traffic load in comparison with MMAC [5], DCA [1], and the IEEE 802.11

It is obvious that by providing multiple channel usage, aggregate throughput is increased by at least twice in this test and the average packet delay is reduced significantly. MMAC protocol seems to provide more realistic approach in terms of hardware requirement, however channel negotiation process could be complicated since different links might show the same interest in channel selection especially when the number of channel availability is small.

From Figure 5 and Figure 6, the method proposed here noticeably achieves better performance than that offers by the IEEE 802.11 and the DCA protocol. It also provides rather close outcome to the MMAC protocol. However unlike the MMAC protocol, it is not restricted to a single ISM band.

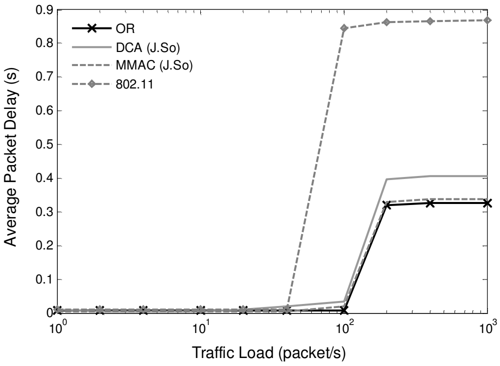

Figure 6: Average packet delay against traffic load in comparison with MMAC [5], DCA [1], and the IEEE 802.11

6. CONCLUSION

This paper proposes the implementation of opportunistic radio in mobile ad hoc network to provide a multi-channel utilization for more efficient use of resources. The test documented in this paper is confined within the extension of WLAN ad hoc networks in order to evaluate the proposed system in comparison with existing approaches in multi-channel MAC protocols as well as the current IEEE 802.11. Simulation results are given and they illustrate an improvement in terms of throughput and average packet delay comparing with the IEEE 802.11 standard and the DCA protocol though rather close performance is observed for the MMAC approach. The key benefit as mentioned is that this approach is not restricted within the same standard. Hence, ongoing work is being focused on the investigation of a larger environment case.

7. ACKNOWLEDGEMENT

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