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Opportunistic channel selection MAC protocol for cognitive radio ad hoc sensor networks in the internet of things

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ABSTRACT

Internet of things (IoT) constitutes networked devices that can gather and exchange information. The scarcity of the available spectrum used by a large number of devices in IoT is a challenge. Spectrum scarcity changes the whole paradigm of spectrum access in order to increase utilization of the limited resource. Cognitive radio ad hoc sensor networks (CRASN) also operate on the same principle and exploit spectrum holes for efficient utilization of the spectrum. In a multi-channel CRASN, the dynamic nature of primary user (PU) activity and the resulting frequent channel switching require an efficient medium access control (MAC) protocol. A channel selection scheme cannot solely perform well without help of the MAC protocol. As a result, most of the channels remain underutilized, and eventually, overall system performance degrades. In this paper, an opportunistic MAC protocol for CRASN is proposed, and is compared to the IEEE 802.11 MAC protocol with round robin and random channel selection schemes. Furthermore, an opportunistic channel selection scheme (OCSS) is proposed. The simulation results confirm the effectiveness of the proposed approach in comparison of the round robin and random channel selection schemes.

1. Introduction

The internet of things (IoT) is growing rapidly in the wireless communications domain. It was first introduced by Ashton in 1999, and the foundation of IoT was laid by Weiser [1]. The IoT consists of sensors, mobile phones, etc. One of its goals is for all connected devices to interact with each other and cooperate with their neighbors [2]. The wireless sensor network (WSN) is the effective medium to be integrated into the IoT [3–5]. Some predict that the number of smart devices will grow to 500 billion [6] by 2020. Another goal of the IoT is to provide reliable connectivity between smart devices. A number of sensors need to communicate with the sink for reading, decision making, etc. Due to spectrum scarcity, we need to rely on technologies like cognitive radio (CR) [7] to increase spectrum utilization and reuse. CR technology can automatically detect the radio environment, tune the transmission parameters, and dramatically improve spectrum efficiency. Therefore, CR can be integrated into the IoT paradigm. The cognitive radio ad hoc sensor network (CRASN) does not have an infrastructure backbone. In a CRASN, each user needs to have all the CR capabilities and, based on local observation, is responsible for all communications [8]. The cognitive radio ad hoc network (CRAHN) [9] is a preliminary model, according to federal communications commission (FCC) guidelines [10], consisting of multi-channel communications. Furthermore, a CRAHN uses the standard IEEE 802.11 medium access control (MAC) protocol with a CR capability for communications.

The widely used CRAHN module is the state of the art in the CR field [11]. Primary user (PU) activity is modeled by the exponential ON-OFF model [12]. An ON (busy) state reflects a channel that is occupied by the PU. The OFF (idle) state shows a channel is available for other communications. A CRAHN follows the cognitive cycle model [13] for CR user activity, and implements channel selection at the link layer or at the routing layer. Link layer management in a CRAHN is the key to maximizing goodput for CR users. The CRAHN implements two channel-allocation schemes: random and sequential. In random allocation scheme, the CR user randomly chooses a channel from among the available channels. Under sequential channel allocation scheme, the CR user selects a channel via round

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robin algorithm. The impact of the channel allocation scheme in a CRASN is still an unexplored research area.

Therefore, in this paper, we propose an opportunistic MAC protocol based on Legacy IEEE 802.11 to intelligently cater to channel switching and to notify the next-hop neighbor to make changes accordingly for seamless communications. There is no impact from the channel switching scheme until it eventually tunes back to the receiver's receive channel. Hence, the proposed method reduces time waste by tuning to a new channel based on the channel selection scheme, improves overall efficiency, increases channel utilization, and eventually increases the overall goodput of the system. Opportunistic channel selection is essential in CRASN to choose the best channel for transmission. It is essential in improving the successful transmission probability of packets with less latency and it eventually increases the overall throughput of the system. Subsequently, energy efficiency can be achieved because more packets can be successfully transmitted within a given time. The role and responsibilities of opportunistic channel selection are to intelligently cater to channel switching and to notify the next-hop neighbor to make changes accordingly for seamless communications. Additionally, it can reduce the time waste by tuning to a new channel based on the channel selection scheme and hence increases the channel utilization and goodput. Therefore, we propose an opportunistic channel selection scheme (OCSS) to further improve the goodput of the system.

The rest of this paper is structured as follows. Section 2 discusses related work. In Section 3, we explain our proposed MAC protocol. Section 4 explains OCSS for the CRASN. Section 5 provides the details of the simulation environment and discusses the results. Finally, Section 6 concludes the paper.

2. Related Work

In [14], a preemptive opportunistic CR MAC protocol was proposed. The proposed protocol consists of three main phases: network initialization, reporting, and contention. An exclusive sensing and preemption mechanism are utilized by the proposed method to transmit data and to report sensing results without collision. The authors concluded that the proposed protocol outperforms over the existing CR MAC protocols in terms of the end-to-end delay and throughput. In [15], a distributed medium access control (DMAC) protocol based for CRAHNs was proposed to mitigate the hidden and exposed node problems of multichannel PUs and SUs. In the proposed protocol, transmit power is adjusted based on the distance between SU and communication pairs. Therefore, the channel reuse and throughput can be enhanced. The authors in [16] proposed an opportunistic MAC protocol for cognitive radio networks. In the proposed scheme, SU contains two transceivers. One transceiver is used for the control channel, while the other is used as a cognitive radio. The authors integrate the spectrum sensing at the physical layer and packet scheduling at the MAC layer, and dynamically utilize the available frequency spectrum.

The large amount of energy is consumed during the processing and transmitting operations of SU in CRANS [17,18]. Therefore, it is important to design a MAC protocol requiring less energy while showing high throughput. The authors in [19] introduced the energy efficient cognitive radio communications for IoT and proposed a channel selection criteria avoiding retransmission in CRAHNs for SUs to utilize the IoT based devices. Their results demonstrate that the proposed protocol shows high throughput with less energy consumption.

The minimum interference based channel selection technique was proposed in [20,21]. They select the channel having minimum interference. However, it lacks maximizing connectivity and in result increases the interference. In [22], authors select the channels covering the maximum number of neighbors. This approach induces interference on those particular channels. SURF [23] is the network layer solution that classifies the channels based on PU occupancy and connectivity. In SURF, a sender and receiver are closely located, and tune to the same channel to ensure effective and reliable connectivity. It also injects too much interference to adjacent channels. CRAHN already caters this problem in spectrum sensing block. Above mentioned channel selection schemes are based on cross-layer collaboration with the lower layers. Hence, the layered approach in communications is broken.

A CRAHN link layer solution based on an interface assignment policy was proposed by Pardeep and Vadiya [24]. It classifies the available interface as either fixed or switchable. A fixed interface stays on a specific channel for a longer time period, whereas a switchable interface can change to other channels. Therefore, all CR users classify one interface as the fixed interface and a second interface as switchable. When CR users require communications with a neighbor node, they adjust the switchable interface to the channel used by the fixed interface of the neighbor node and start transmitting. Every interface implements a spectrum-sharing scheme based on carrier sensing multiple access with collision avoidance (CSMA-CA) using acknowledgment (ACK) and frame retransmissions at the MAC layer. The CRAHN extends the MAC scheme to consider interference induced by PU on a CR user. When a CR user starts receiving a packet from another CR user, it checks two conditions: first is if the PU transmits on the same or an adjacent channel, and second, if the receiver starts transmission at the time of reception. Under either of those conditions, the CR receiver will calculate the power injected by the PU on the given channel and the actual signal-to-interference-plus-noise ratio (SINR). If the SINR is below a given threshold, the CR receiver discards the packet from the CR sender.

Under the IEEE 802.11 distributed coordination function (DCF) protocol [25], a sender ensures that the medium is idle before attempting to transmit. It selects a random backoff interval less than or equal to the current contention window (CW) size, based on the uniform distribution, and then decreases the backoff timer by 1 for each time slot in which the medium is idle. If the medium is determined as busy, the station will suspend its backoff timer until the end of the current transmission. Transmission commences when the backoff timer reaches zero. When there are collisions during transmission, or when transmission fails, the station invokes the backoff procedure. To begin the backoff procedure, the contention window size, CW, which takes an initial value of CW_{min}, doubles its value until it reaches the maximum upper limit, CW_{max}, and remains at the CW_{max} value, when reached, until it is reset. Then, the station sets its backoff timer to a random number uniformly distributed over the interval [0, CW]and attempts to retransmit when the backoff timer reaches zero again. If the maximum transmission failure limit is reached, the retransmission stops, CW is reset to CW_{min}, and the packet is discarded [26]. The access mechanism of IEEE 802.11 is shown in Fig. 1. Fig. 2 depicts the request to send (RTS) frame structure. In frame, RA is the address of the intended receiver. TA is the address of the sender. The duration value is the time in microseconds required to transmit the data frame, the clear to send (CTS) frame, the ACK frame, and three short interframe space (SIFS) intervals. The SIFS is the minimum interframe space. The sender transmits RTS to the receiver and on successful reception of the RTS frame, the receiver responds with a CTS frame. A frame check sequence (FCS) is used to determine integrity of the frame. Fig. 3 shows the CTS frame structure. The RA holds the RTS sender's address, which is copied from the RTS TA field. The duration value is calculated by subtracting the time required to transmit CTS and the SIFS interval from the duration field of the received RTS frame. The neighboring nodes of both sender and receiver, overhearing the RTS and CTS frames, defer their transmissions for the time specified in RTS/CTS duration field. Therefore, all the nodes maintain a

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