Dynamically Assigned Channel for Wireless Sensor Network: A Regret Matching Based Approach

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Abstract— Several channels in Wireless Sensor Networks (WSNs) are widely exploited to support parallel transmission and to minimize interference. However, the extra expense posed by the multi-channel usage coordination dramatically challenges the energy constrained WSNs. In these paper, we applied a Regret Matching based Channel Assignment algorithm (RMCA) to address this challenge, in which each sensor node updates its choice of channels according to the historical record of these channels' performance to minimize interference. The advantage of RMCA is that it is highly distributed and requires less information exchange among sensor nodes. It is proved that RMCA converges almost right to the set of correlated equilibrium. Moreover, RMCA can be adapted channel assignment among sensor nodes to the time-variant flows and network topology. Results show that RMCA reaches better network performance in words of both delivery ratio and packet latency than CONTROL, MMSN and randomized CSMA. In addition, real hardware experiments are organized to apply that RMCA is simple to be implemented and performs better.

Index Terms—Channel assignment, regret matching, correlated equilibrium, wireless sensor network.

I. INTRODUCTION

In general, many applications of Wireless Sensor Networks (WSNs) such as environment monitoring, medical care, target tracking, etc. may present in the same geographical region, as a result, the high sensor node density may affect the communication interference among sensor nodes. Single channel MAC protocols cannot handle this surging interference expensively. Moreover, current sensor nodes, which are usually provided with one simple half duplex transceiver, are able to operate on several channels. IEEE 802.11 standard for wireless communication provides several channels availability. By using multi channel assignment, the sensor network can benefit better performance. Hence, it is attractive to exploit several channels in WSNs to support parallel transmission and minimize interference in the highly dense sensor networks. Recently, there have been a considerable number of studies on multi-channel usage in wireless networks. However, most of the existing works make some strong assumptions that the radio transceivers either use the frequency hopping spread spectrum wireless cards or can operate on multiple channels at the same time. Unfortunately, such assumptions do not hold in WSNs, because current available sensor node has only one simple half-duplex radio transceiver. In addition, the extra expense due to dynamic channel negotiations poses significant challenges to WSNs with constrained energy and limited bandwidth. Present most of multi-channel protocols have been proposed specially for WSNs and they can be divided into two types. The first type is to assign channels in a static way based on the static network topology assumption. These protocols cause much shorted communication overhead. However, since they do not track the sudden transmission flows when presenting channels, they can construct the links involved in the transmission flows bandwidth-tight but that not involved in the transmission flows bandwidth-excess. Moreover, both the network topology and the transmission flows are time-variant in practice. Thus, static channel assignment is not an expense way to correct interference. The second category is to dynamically assign channels to links according to the sudden transmission flows. The MAC protocol for WSNs is designed and implemented on sensor motes with no specific assumptions on the application. The paper activity on how to incorporate both the advantages of multiple channels and TDMA into the MAC design with low expense. The study applied an energy efficient multichannel MAC protocol, Y-MAC, for WSN to reaches both high performance and energy efficiency under diverse traffic conditions. A FDMA channel assignment in a non-cooperative wireless network is studied. The authors present an adaptive dynamic channel allocation protocol (ADCA) in wireless mesh network, which contains both static and dynamic interfaces. The study proposes a channel assignment scheme for the cognitive radio networks (CRNs) can be balanced rate maximization and network connectivity. They mainly activity on CRNs in which every node is useful with their multiple radios. It presents comprehensive survey on spectrum assignment in cognitive radio networks in spectrum assignment. This system applied a dynamic spectrum assignment algorithm to increases the number of secondary users that to be satisfied in terms of throughput in the centralized CRN. Although these protocols can minimize interference some exchange message globally or in a big neighborhood to perform channel based usage negotiations and coordination. Therefore, they cause considerable amount of communication overhead to WSNs. Hence, an expense channel assignment method for WSNs should be highly distributed with very short information exchange. First, we applied a highly distributed Regret Matching based Channel Assignment algorithm (RMCA). RMCA converges right to the set of correlated equilibrium, in which the action of individual sensor node is a best response to its environment and for the actions of remaining sensor nodes so that the whole network achieves a reasonable arguably performable network performance. RMCA also adapt the channel assigned dynamically of to the time-variant transmission flows in the network to reduce interference effectively. Simulation results of both the fixed flows and time-variant flows scenarios shows that RMCA reaches the better network performance than REGULATING, MMSN and randomized CSMA. Secondly, we are implemented RMCA in real test bed and calculate its performance .The experiment results demonstrate that: (1) RMCA is very convenient to be demonstrate in the real hardware system; (2) RMCA able to make the sensor nodes in the identical collision domain using different channels; and (3) RMCA reaches the better network performance in terms of both delivery ratio and packet latency than MMSN and randomized CSMA. The remainder of the system is conducted as follows: Section 2presents system model and describes the channel assignment problem effectively. Section III. proposes the regret matching based channel assignment algorithm for the channel assignment problem. The performance of the applied algorithm is calculated by the extensive simulations and experiments in Section IV. We conclude this system in section V.

II. MODELLING OF THE SYSTEM AND PROBLEM DESCRIPTION

2.1 MODELLING OF THE SYSTEM

Consider a sensor network with several nodes. Every sensor node is appropriate with single simple half duplex transceiver, and is able to operate on several channels. Many over, every node can only choose individual channel to deliver packet at every stage We consider that the assigned channels are all of non overlapping and do not interfere with every remaining, e.g., the channels which are at least two channels away from each remaining in the IEEE 802.15.4 compatible CC2420 chip are such as non-overlapping channels . In addition, we select single channel from the available channels as a regulating channel to broadcast the channel assignment information.

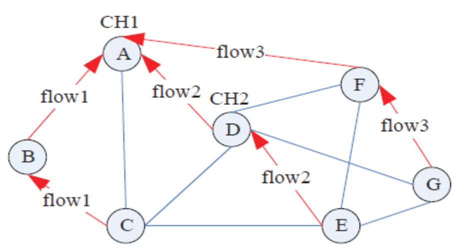

Fig 1: An example of sensor network composed of seven sensor nodes with three transmission flows

We assign the channels to sensor nodes in a get-centric way. Every sensor node selects a channel to get packets, and broadcasts this information for its neighbors through the regulating channel. The neighbors with packets to delivery to the node should use this channel to send the packets. As furnished in Fig. 1, sensor node *A* uses *CH*1 to get, and thus sensor nodes *B*, *D* and *F* can use *CH*1 to transmit their packets to *A*. Further many, sensor nodes, which are in identical collision domain and using identical channel for transmission, perform CSMA/CA to contend for the medium access.

2.2 Problem Description

The interference suffered by the sender is quite related to the number of the neighbors which use the identical channel to send packets as the sender. For example, in Fig. 1, if *C*, *G* and *F* also use *CH*2 to send packets, hence the transmission from *E* to *D* would be interfered with by the transmissions of *C*, *G* and *F*.

Therefore, *E* may perform many retries and even suffer collision. Many over, in the get-centric channel assignment way, the channel the sender uses to send is determined by the transmission, and the sender relationship is determined by the flows in the network and the network topology. Therefore, the interference suffered by the network is quite related to the flows and network topology. Since the flows and network topology are usually of time-variant in practice, the channel assignment should have been tracked the sudden flows and the time-variant network topology to decreases Interference. Therefore, co-ordinations among sensor Nodes are compulsory. However, these co-ordinations usually of result in large overhead to the network and challenge of the energy constrained WSNs. Such impact of the coordination packets has been studied by simulations. It's results reveals that the network throughput break down erroneous with the data packet length decreasing. It's also points out that the coordination packets brought by channel usage negotiation play a remarkable role in harming the network performance in WSNs, where the length of data packet is usually of quite short and comparable to that of coordination packet. Therefore, reducing coordination packets is a critical goal when planning dynamically channel assignment algorithm. In this system, instead of explicitly coordinating, every sensor node only relies on a history of its observations to predict the environment variation and the actions of remaining sensor nodes, and hence selects a channel to respond to this prediction. This observation is only a noisy aggregate indicator of the environment and the actions of remaining sensor nodes, rather than explicit observations of remaining sensor nodes. Thus, very Short information is exchanged, and energy Consumption is potentially of minimized. Further many, all of the sensor nodes provide an immediate response to the variation of the flows and network topology, and the response can be improved over time.

III. REGRET MATCHING BASED CHANNEL ASSIGNMENT

3.1 Metrics to measure radio interference

We conduct a group of experiments to study the interference suffered by single sensor node. Three main *t* metrics—Packet Delivery Ratio (PDR), Valid Receiving Ratio (VRR) and Average packet Transfer Delay (ATD)—are considered to calculated the degree of interference. For a sensor node receiving packets, some of them are sent to it and called of valid packets when remaining are not sent to it but expense by it. In this case, VRR is defined as the ratio of the valid packets the sensor node has pick up to all of the packets heard by it. ATD is defined as average packet transfer delay of all of the valid packets. The experiments are organized with sensor nodes. Twelve nodes are placed on a 4-by-3 grid with every edge equaling to 25cm. In such a deployment, every node can be hearing from the remaining 11 nodes. Sensor node *A* is sending packets to sensor node *B* constantly, when the remaining sensor nodes use the identical channel to send packets constantly, which interfere with the communication between *A* and *B*. We call of these sensor nodes interference nodes. All of sensor nodes perform CSMA/CA to contend for medium access. We change the number of interfering sensor nodes from 0 to 10. In every round for the identical channel in that experiment, *A* tries to delivery 5000 packets with packet length of 50 bytes to *B*. The PDR, ATD and VRR of the link *A* toward *B* are furnished in Fig. 2. It can seen that when the number of interfering nodes increases from 0 to 10, PDR decreases from 99% to 42%, VRR decreases from 100% to 11%, and ATD increases from 5ms to 20ms. These observations can be explained as follows. First, VRR reflects the number of sensor nodes contending for the access to the sensor node *B* uses in its collision domain, i.e., many interfering sensor nodes lead to a smaller of VRR. Second, ATD reflects the time that a packet toward sensor node *B* should try for a successful receipt, i.e., many trying time results in a longer delay and this indicates larger interference. In addition, when the interference increases, the number of interfering nodes increases, PDR and VRR decrease accordingly when ATD increases. Thus, PDR, VRR and ATD can represent the interference suffered by the sensor nodes in a great degree. In addition, PDR wants to gather information from both source and sink at the identical time, when both VRR and ATD can be calculated independently without explicit requirement of the information of remaining sensor nodes. VRR also reflects the network performance in term of delivery ratio and ATD reflects the network performance in term of packet latency as well. In order to simplify the data collection in real application as well as to properly measure the interference, we choose VRR and ATD as the metrics to characterize the interference.

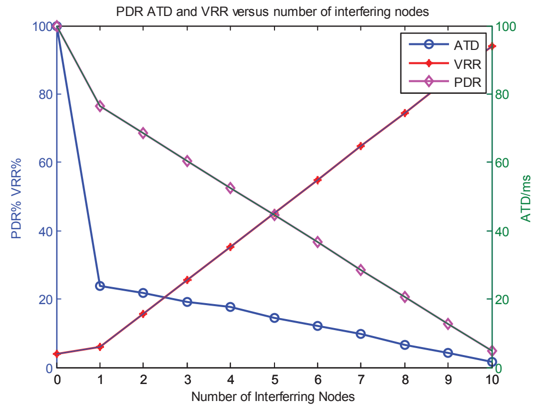

Fig2: PDR, ATD and VRR Vs number of interfering nodes.

IV. SIMULATION RESULT

4.1 Evaluation by Simulation

We calculated the network performance of RMCA by simulations in this section. We use MATLAB to comparing RMCA with the dynamic assignment algorithm proposed MMSN and randomized CSMA multiple channel assignment algorithm in terms of packet delivery ratio and latency. The main idea is “CONTROL” that nodes exchange state information about messages received and degree of estimated communication success probability, which can be regarded as feedback from the perspective of control. The main idea of “randomized CSMA” is that separate node randomly selects a channel to perform CSMA at individual stage. We conducted the even-selection of MMSN, which can be used when non-overlapping channels is not sufficient and leads to less interference. In all results, the time parameters of sensor nodes are accordance with CC2430 [32], 50 sensor nodes are deployed randomly in a 100m×100m field, and the communication radius of individual sensor node is 40m.. The network routing is organized as a tree and the network topology is fixed all simulations. Individual flows from a leaf to the root and its data rate is 56 Kbyte/min. All the sensor nodes randomly select a channel to receive packets at the initial stage of RMCA. To evaluate the ability of RMCA to handle interference, we perform the first group of simulations, in which the flows in individual simulation are fixed throughout the simulation. The flows are randomly generated at the beginning of the simulation. We change the number of flows from 3 to 7, and show the network. Compare RMCA with CONTROL, MMSN and randomized CSMA in terms of packet delivery ratio and latency for static flows performance of RMCA, CONTROL, and MMSN and randomized CSMA. Individual point is the average result of 50 independent simulations. We have the following observations. Firstly, RMCA outperforms CONTROL, MMSN and randomized CSMA in terms of both delivery ratio and packet latency. The average delivery ratio of RMCA is larger than the ones of CONTROL, MMSN and randomized CSMA. We have the similar observation for the packet latency. This is because, instead of statically assigning channels, RMCA can adapt the channel assignment to the transmission flows and achieve no regret. Secondly, the advantage of RMCA over MMSN and randomized CSMA becomes more remarkable with the increase of the number of flows. When the number of flows increases, the average differences in delivery ratio between RMCA and MMSN or randomized CSMA become larger, and the average differences in packet latency obtained smaller. This is because that the increase of flows exacerbates the interference and provides more chance for RMCA can be adapted the channel assignment among sensor nodes to achieve better network performance. Notice that the dynamic channel assignment CONTROL seems to reaches the worse performance than the static MMSN, because MMSN always involves multiple channels regardless of the network load when CONTROL has small chance to hop from the initial channel when network load is light. Actually, we can find that the performance of CONTROL slowly surpasses MMSN when the number of flows increases To calculated the ability of RMCA to track the variations in environment, we conduct the second group of simulations, in which the flows in one simulation are time-variant. We set the number of flows to 4, and vary the frequency of flows from 2 times per simulation to 10 times per simulation. In each time flows are regenerated randomly. The network performance of RMCA, CONTROL, MMSN and randomized CSMA is shown in Fig2. Each point is the average result of 50 independent results. We observe the following. Firstly, RMCA outperforms CONTROL, MMSN and randomized CSMA in terms of both delivery ratio and packet latency. Secondly, the performance of RMCA keeps almost the same with a slight improvement while that of CONTROL decreases, when the frequency of flows varying increases. Since both MMSN and randomized CSMA are static channel assignment methods, their network performance are not quite related to the frequency of flows varying. On the contrary, the performance of dynamic channel assignment method such as CONTROL usually degrades with the frequency increasing. Thus, the second observation implies that RMCA can track the variation of flows in some degree. To illustrate the adaption in RMCA, we snapshot an adjusting process in Fig3. When the variation flow take place at stage 3000, and compare RMCA with MMSN and randomized CSMA. The flow variation indicates that both the source node and sink node of the flows change. In this simulation, all the sensor nodes select the same channel to receive packets at the initial stage of RMCA. The delivery ratios of randomized CSMA, MMSN and randomized CSMA are decreasing after stage 3000.Both MMSN and randomized CSMA/CA drop directly to the next stable delivery ratios, but RMCA first drops and then climbs up to the next stable delivery ratio. This is because that RMCA immediately learns the inexpensively of current channel assignment from the average regret and adapts the channel assignment to the flows variation. The observation of packet latency is similar to the delivery ratio. The large spikes of RMCA in Fig. 3 result from the tremble over channels in the adjusting process.

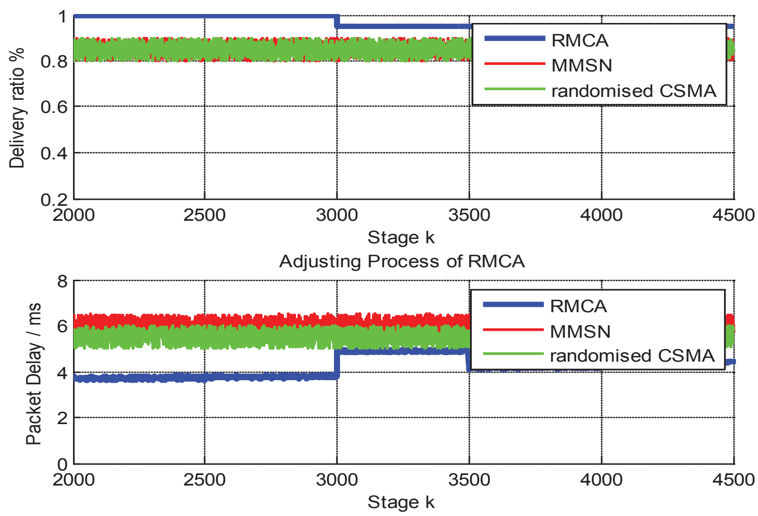

Fig3: An adjusting process of RMCA

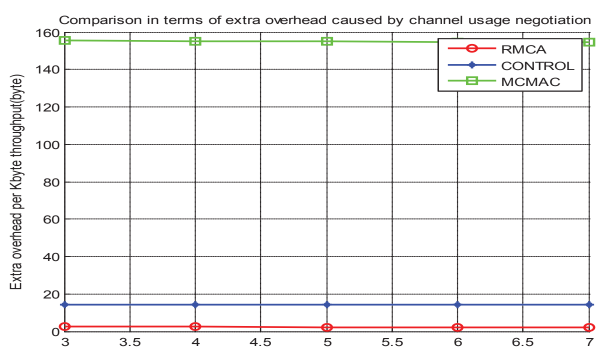

Fig 4: comparison in terms of extra overhead caused by channel usage negotiation

To evaluate the performance of RMCA in reducing extra overhead caused by channel usage negotiation, we conducted third group of simulations to comparing RMCA with two typical dynamic channel assignment algorithms—MCMAC and CONTROL. In this group of simulations, the periods of RMCA and CONTROL are the same. Since they both reconsider the channel assignment periodically. We depict the results in Fig.4, where each point is the average result of 50 independent simulations. As shown in Fig.4, per Kbyte throughput, RMCA causes the least extra overhead about several bytes; CONTROL causes an extra overhead about tens of bytes, and MCMAC results in the most one about thousands of bytes. In addition, Fig. 6 shows that with the network load (number of flows) increasing, the extra overhead per Kbyte throughput of RMCA and CONTROL decreases while that of MCMAC increases slightly. These observations are consistence with the designs of these algorithms: RMCA exchanges coordination packets only when the channel used by sensor node changes, CONTROL exchanges coordination packets periodically, and MCMAC exchanges coordination packets for each transmission. Due to the reduction of extra overhead, both of the communication complexity and computation complexity can be reduced, which helps to save energy for WSNs.

4.2 Calculated by Test-bed Experiment:

We further conduct a series of test-bed experiments to calculate the performance of RMCA comparing with MMSN and randomized CSMA. In these experiments, we use Imote2 sensor node, which contains the Marvell PXA271 X scale processor at 13-416 MHz, including a Marvell wireless MMX DSP coprocessor. It is appropriate with the IEEE802.15.4 radio compatible transceiver (CC2420) which supports 250kb/s data rate with 16 channels in the 2.4 GHz band. We use USB client with on-board mini-B Connector and Host Adapters to connecting Imote2 in computer. GCC in Linux is used to realize channel assignment algorithms—RMCA, MMSN and randomized CSMA. In this experiment we consider twelve sensor nodes are surrounded in a 4-by-3 grid with each edge equaling to 90 cm. In addition, there is a base sensor node with two functions: 1) To set the values transmission process; and 2) sending beacon packets to each of the operating 12 sensor nodes occurring to synchronize them. The base sensor node uses the highest power to send beacon packets, which ensures that other nodes can hear from it. There are 6 end-to-end flows with one source and one sink node for each flow. The common control channel is 2415 MHz; three data channels are 2430 MHz (named as channel #1), 2450 MHz (channel #2), and 2470 MHz (channel#3). These four channels are not adjacent from each other, in order to avoid the interference among adjacent channels. The time is divided into stages and each stage is composed of two sub-stages: coordination packet time and data packet time. During coordination packet time, coordination packets about the channels exchange, while during data packet time, data packets exchange. The length of data packet time is chosen to be 5 seconds. And at the initial stage for RMCA, sensor nodes randomly select a channel to receive packets. The first group of experiments is to check the validity of RMCA. During the data packet time, the sources of 6 flows send one packet with packet length of 50 bytes every 30 ms. after the data packet time, sensor nodes enter coordination packet time. They send their new channel choice information packet to each other and will be synchronized by the beacon packet from the base node. After synchronization, sensor nodes can send their packets almost at the same time, so that we can check how effective RMCA can help adjust the channels according to interference. It should be noticed that though the sensor nodes are of the same type, their oscillating frequency and inner timer are slightly distinctive, and that is why sensor nodes do not send packet at the same time exactly. Fig5 shows the change of two network performance metrics (i.e., packet latency and delivery ratio) when stage *k* increases. From stage 1 to stage 400, average packet latency varies from4.96 ms to 4.92 ms, and packet delivery ratio increases from94.2% to 95.6%, after a small drop to 94%. The results indicate that sensor nodes have better performance by the adjustment of RMCA. The first group of experiments can also be used to check the effectiveness of RMCA, i.e., how RMCA can adjust neighbor nodes using different channels. The topology in these experiments makes sensor nodes able to hear from part of the other nodes. Generally, one of the source nodes (node A) is sending packets, if another node (node B) can be successfully received more than 90% packets that A sends, then B is within A's transmission range. It turns out that most of sinks are within transmission range of most sources, however, there are exceptions. For deployment depicted node 12 is not within node 1's transmission range, node 2 is not within node 11's, and node 10 is not within node 3's and node 1's.TABLE 2 provides how channels have been assigned in the experiment. For each flow, there is one main channel assigned, which takes more than 50% channel occupation in more than400 stages. And the 3 main channels are equally occupied: channel #1 for flows 4 and 5, channel #2 for flows 1 and 6, and channel #3 for flows 2 and 3. The result just shows that RMCA can assign different channel equally. Moreover, according to RMCA, if two flows' sinks are within the transmission range of each other's source, they should try the best to avoid staying in the same channel, in order to decrease interference. For example, the sinks of flow 2 and flow 4 can hear from each other's source, and indicate that their channel assignment is quite complementary, which is exactly result to be achieved by using RMCA. While the sinks of flow 1 and flow 6 is not within transmission range, and they have both taken channel #2 as their main channel without bearing much interference. For RMCA, the parameter settings are the same as described above. For MMSN, there are 3 channels used to transmit data packets and one common channel used to transmit coordination packets. These channels are exactly the same as RMCA channel settings. Randomized CSMA uses multiple channels to transmit packets for all the 12 sensor nodes and base node. For MMSN and randomized CSMA, the 12 sensor nodes also receive beacon packets from the base node periodically to synchronize themselves. In order to fairly compare with RMCA, MMSN and randomized CSMA also divide their time into stages which are composed of data packet time and coordination packet time. In data packet time, sources of flows are set to send packets of 50 bytes length, with time interval of 30ms, 50ms and 100ms, in order to compare network performance under different network loads. In the coordination packet time, twelve sensor nodes process data and receive beacon packets from the base node. For network performance evaluation, both average packet latency and average delivery ratio are the main metrics for comparison among RMCA, MMSN and randomized CSMA. The results depicted in Fig5 are the average of 6 flows after 400 stages. As illustrated in Fig5, with time interval increasing and the network load decreasing, delivery ratio increases for all algorithms, which makes senses theoretically. In addition, Fig5 shows that RMCA achieves higher delivery ratio than MMSN and randomized CSMA do, and their delivery ratio differences increase when the network load gets heavier. The comparison result for average packet latency of the 6 flows is depicted in Fig6. Firstly, a Fig 6 show that as the network load becomes lighter, i.e., the longer time interval to send packets, the packet latency gets shorter. Actually, packet latency varying range is bounded, because back off time after collision in such condition only occupies a small part of the total time taken to send a packet. In addition, Fig6 shows that RMCA almost outperforms MMSN and randomized CSMA .We evaluate network performance of RMCA comparing with two existing algorithms from different perspectives, by conducting two groups of experiments based on Imote2 sensor nodes. The first group shows network using RMCA has great ability to adjust channel assignment gradually and dynamically to reduce interference in neighborhoods. Such channel adjustment makes RMCA achieve better network performance such as higher delivery ratio and shorter packet latency, and also makes RMCA flexible enough to deal with network flow and topology variation. Correspondingly, MMSN cannot adapt to flow and topology changes. In the second group, RMCA outperforms the other two algorithms for packet delivery ratio and average packet latency, when time interval to send packets varies from 30ms to 100ms. The two groups of experiments altogether indicate that RMCA is an effective channel assignment algorithm, both for network performance and dynamic network adjustment.

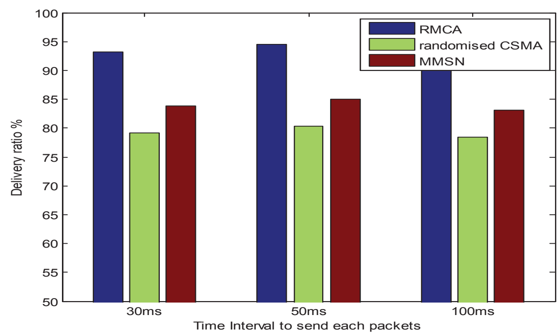

Fig 5: comparison of average packet delivery ratio for RMCA, MMSN and randomized CSMA

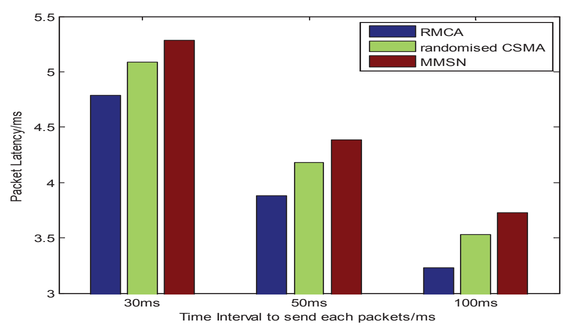

Fig 6: comparison of average packet delivery ratio for RMCA, MMSN and randomized CSMA

V. CONCLUSION

In this paper, we have studied the dynamic channel assignment in WSNs to exploit parallel transmission and minimize interference. Different from existing dynamic channel assignment protocols, we have considered the challenges posed by the multi-channel coordination to the energy constraint of WSNs, and applied a Regret Matching based Channel Assignment algorithm (RMCA). RMCA is mostly distributed and exchanges very less information for sensor nodes to dynamically select channels. It converges almost surely to the set of correlated equilibriums. To tend toward equilibrium implies that all sensor nodes most desirable respond to the environment and to the actions of other sensor nodes. The whole network can also achieve a reasonable quality network performance. Moreover, RMCA can modify the channel assignment among sensor nodes to the time-variant flows and network topology, and improve the network performance over time. Results of both fixed flows and time-variant flows scenarios, and test-bed experiments make something clear that RMCA can achieve better network performance than CONTROL, MMSN and randomized CSMA in terms of delivery ratio and packet latency.

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