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Article

Centralized Control for Dynamic Channel Allocation in IEEE 802.15.4 Based Wireless Sensor Networks

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Abstract. Coexistence problem is one of the most important issues in the IEEE 802.15.4 based Wireless Sensor Networks (WSNs), since the system operates on the highly populated 2.4 GHz ISM band. As a result, system performance of WSNs can be greatly impaired by the interference from over powering signal from other systems such as WLAN and Bluetooth. This paper proposes an approach based on centralized control for dynamic channel allocation. The proposed method offers multi-channel utilization with intelligent controlling mechanism in order to provide system performance enhancement in order to cope with variation of interfered environment. Based on centralized control, decision making process is performed by the network coordinator allowing such system flexibility. Simulation model has been developed and it is embedded with this proposed mechanism in order to test the system performance. To observe the system performance under the proposed method, variety of simulation scenarios are performed with the variation of two major factors affecting system performance including the size of the network topology and the scale of interference. Proposed method is evaluated and the simulation results are compared against tradition system as well as system with multi-channel utilization method with channel scheduling. The flexibility of the method proposed here allows the system to have better system performance under different test scenarios both in terms of average packet end-to-end delay and system throughput.

Keywords: Wireless sensor network, IEEE802.15.4, multi-channel utilization.

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1. Introduction

Currently, the unlicensed Industrial, Scientific and Medical (ISM) band of 2.4 GHz is highly populated with an increasing demand for wireless communications. Wireless Sensor Networks (WSNs) based on the IEEE 802.15.4 standard are among such systems operating on this 2.4 GHz ISM band. Sharing frequency band with other highly used systems such as WiFi and Bluetooth, coexistence problems become unavoidable. Sensor nodes usually transmit with low power to provide energy efficiency for battery-powered devices. Therefore, IEEE 802.15.4 based sensor nodes can be greatly affected by other overpowering devices operating on the same shared frequency band in the same area. In other words, coexistence normally causes more severe problems degrading system performance of WSN than other systems such as WiFi, whose devices typically use higher transmit power.

Large amount of works are dedicated to the development of solutions to the coexistence problems in IEEE 802.15.4 based WSNs. One of the most focused areas is under the development of approaches for multi-channel utilization. In [1] the authors proposed method for multi-channel utilization by frequently detecting interference and switching the entire network to operate on another available channel when being interfered. The limitation of such system is that it is suitable for a star topology and small scale network, where entire network can simply changes channel together. For a larger scale networks, [2] and [3] propose the channel switching algorithm, which only a group of interfered nodes perform channel switching to use an available channel. The approaches provide more flexible channel allocation, however the decision making is done locally without any central control. Therefore, the overall system performance is not considered. Authors of [4] proposed the channel scheduling for multi-channel usage, in which all devices need to synchronize with the common channel hopping pattern. Although all devices need to switch channel with the fixed interval at all time, the system is benefit from no continuous channel detection needed. Nonetheless, the approach is based on the hopping pattern with fixed number of channels. Therefore, assigned number of multiple channels influents system performance and one fixed pattern may not be suitable for changing interference environment.

As a result, better optimization technique is needed to overcome such mentioned drawbacks. The motivation of this work therefore comes from the need to further enhance system performance under coexistence problem as well as to provide more flexibility to the WSN in handling possible changes of system environment.

In this paper, dynamic channel allocation scheme based on centralized control is proposed. Simple decision making is developed to consider the system environment and it is performed by the central controller, in this case a network coordinator. Based on the current situation, decision can be made to switch entire network to an available channel or operating on a multiple channel scheduling.

The rest of the paper is organized as follows. Section two introduces multi-channel utilization in WSNs. In section three, the proposed centralized control for dynamic channel allocation is illustrated. Section four presents the simulator model used in this work as well as the test scenarios. Simulation results are then given in section five. Finally, the paper is concluded in section six.

2. Multi-Channel Utilization in Wireless Sensor Networks

2.1. Multi-Channel Utilization: Needs and Challenges

Duarte-Melo et al. [5] have studied the data delivery capacity in order to identify its limiting factors and try to describe existing method to overcome such limitations. From [5], interference and contention on the wireless medium are one of the major limiting factors and they can be eliminated through multi-channel communication. In WSNs, the traffic is usually towards a network coordinator, which results in many-to-one communications. Duarte-Melo et al. therefore studied the capacity of WSNs in many-to-one data gathering scenarios. As a result, they have identified major constraints including interference and contention on the wireless medium, limited bandwidth, and the topology of the network. Considering limited bandwidth, the achievable data rates are around a few tens of kilobits per second showing the interference impact on the network capacity

Looking into the constrains as mentioned, network topology impacts the data collection performance hence effecting system capacity since WSNs are usually based on many-to-one communication paradigm. In such paradigm, data from sensor nodes will be sent to the coordinator (sink node) and usually being relayed over tree type routing topologies. Hence, contention to transmit data from multiple sensor nodes to the network coordinator is unavoidable. Changing network topology from single stat to multiple-hop line topology would result in different network capacity.

Although multi-channel utilization supposes to be one of the best candidates to maximize concurrent transmissions providing network's capacity enhancement, there are some challenges. Channel overlapping or adjacent channel interference is one of the main challenges in multi-channel utilization, since not all the channels specified by communication standard are non-overlapping from each other. For example, there are only three non-overlapping channels based on channel arrangement of IEEE 802.11 out of all 11 channels. Hence, only these three channels are orthogonal to each other and most users would configure their wireless interfaces to use one of these three channels. Nonetheless, careful use of more than three channels with tolerable level of interference could significantly improve the system performance. Studies shown in [6] that the data delivery can be significantly influenced by not only co-channel interference but also adjacent spectrum interference. The usage of overlapping frequencies would need to be carefully considered when designing multi-channel utilization technique. In [7], the performance gained with the usage of overlapping channels over using only the orthogonal channels was examined as well as the relationship between channel orthogonality and network capacity. Conclusion obtained from the work is that using overlapping channels, which constitute a much smaller band, provides more efficient use of the spectrum. Hence, enhancing network performance as well as achieving better spectrum utilization can be done through the use of overlapping channels while keeping acceptable level of interference.

In order to provide multi-channel communication, one fundamental aspect would be the channel switching function, which allows radios to dynamically switch between channels in order to avoid interference. General radios would come across certain channel switching delay for example around 200μs based on CC2420 radios [8], which are used on WSN motes. As a result, it is obvious that any techniques that need often channels switching would suffer from high overhand of switching delay. Therefore, channel switching should be highly considered as one of the factors affecting the performance of system under any multi-channel utilization schemes.

Coordination between nodes in WSN with multi-channel utilization is one very important issue in multi-channel utilization since all the radios in the network might not be on the same channel at the same time, however they need to coordination for which channel to be used and when. This issue offers more challenges to the single-radio transceivers than those with multiple radios and could cause rather serious problems such as multi-channel hidden terminal problem and the problem to provide broadcasting of data to switching nodes.

2.2. Channel Assignment in Wireless Ad Hoc Networks

WSNs are considered as a sub-class of wireless ad hoc networks, which is a collection of wireless devices that self-configure to form a network without the use of any established infrastructure. Capacity of WSNs and the challenges in implementing multi-channel unitization has been introduced in the previous subsection. This subsection will discuss the existing channel assignment methods for wireless ad hoc networks that are based on multi-hop communication techniques and work with a single radio. The existing methods of channel assignment algorithms and multi-channel MAC protocols for wireless ad hoc networks are classified according to their requirements and mode of operation.

Fixed channel assignment: The basic idea of fixed channel assignment approaches is to cluster the nodes and each cluster only uses a single channel, which is different from the channels that are assigned to the other clusters that may cause interference. The main advantage of fixed channel assignment approaches is the ease of implementation since the dynamics due to channel switching and variations in the network topology are not considered. However, fixed channel assignment enforces the nodes to keep their interfaces on a particular channel leading to some drawbacks such as nonadaptive to dynamic network conditions and unable to communicate if transceivers of two neighbouring nodes are fixed on different frequencies. Vedantham et al. [9] came up with rather different idea from clustering, however with fixed channel assignment. They introduced the concept of component-based channel assignment induced by a flow graph between sources and destinations. All links in the connected components are assigned a single channel and operate on the same channel throughout.

Semi-dynamic channel assignment: In these approaches, fixed channels are assigned either to the senders or receivers and the nodes can switch their interfaces on the selected channels to communicate with other nodes. In [10], the authors proposed the use of graph-based approaches to solve channel assignment problem. An advantage of semi-dynamic approaches over the fixed channel assignment is that nodes can switch to different channels to communicate with different neighbours such that partitions can be eliminated. On the other hand, with semi-dynamic channel assignment approaches a detailed coordination of channel switching is required between the senders and receivers in order to be on the same channel at the same time. The problems that arise due to the channel switching are multi-channel hidden terminal problem, deafness problem, and broadcast support.

Dynamic channel assignment: In dynamic channel assignment approaches, every data transmission takes place after a channel selection. The channel selection can be measurement based or status based. In measurement based approaches, the communicating parties measure the Signal-to-Interference-plus-Noise Ratio (SINR) values on a channel before transmitting. In status-based approaches, nodes keep track of the status of the channels, such as busy or idle, according to the received control packets. Dynamic channel assignment approaches share the problems of semi-dynamic channel assignment approaches. Dynamic channel assignment is further classified into four categories based on the methods of coordination:

1) Dedicated Control Channel: This approach require dedicated control channel for the transmission of control packets [11, 12]. These control packets are used for the purpose of channel negotiation and notification. The method is simple, however reducing spectral efficiency from the use of one channel purely for the management purpose. It is also necessary that the device needs to have two radios so one can be tuned to listen to the control channel at all time while the other one is used for data communication. This leads to higher cost and complication on the end devices.
2) Split Phase or Time Division: This approach requires only one radio for each device. In this technique, the channel negotiation process is performed on a control channel however within a specified timeslot. The communication can then be carried out in the next timeslot (dedicated for data transmission) on the agreed channel. This agreed channel can also be the same as the control channel since the data transmission and control packet transmission are assigned in different time period. The method is based on time division approach to separate time into the control period and the communication period. In this type of methods, timing synchronization is necessary. Nevertheless, the approach benefits from the use of all available channels for data communication in the data transmission timeslots avoiding the single control channel bottleneck especially when number of available channel is low. Multi-Channel MAC (MMAC) [13], Multi-Channel Access Protocol (MAP) [14] and TMMAC [15] are examples of protocols that are based on time division access.
3) Frequency Hopping: This approach does not require any dedicated control channel or the channel negotiation process. Proposed in [16] and [17], the channel hopping approaches are used. Devices do not negotiate on the operating channel. On the other hand, they hop from one frequency to another together using the known channel hopping sequence. As a result, only one radio is needed. However, timing synchronization becomes very curtail. Further adaptations to originally proposed idea are also presented in [18] and [19], where several hopping sequences are employed. The hopping patterns are previously set or generated randomly.

As mentioned, WSNs are defined as a sub-class of wireless ad hoc networks. Hence, the proposed techniques for multi-channel communication in wireless ad hoc networks can be a guideline used while designing protocols for WSNs. However, general wireless ad hoc networks are usually composed of nodes (laptop computers, palmtops, personal digital assistants (PDA) or other information devices) with more complex radios and can run protocols such as IEEE 802.11, which is costly in terms of energy consumption for the resource constrained sensor nodes. Therefore, the main differences between the two types of networks should be taken into account as well as consideration on the characteristics of WSNs while designing the protocols.

3. Proposed Centralized Control for Dynamic Channel Allocation

As mentioned, most of the previously proposed schemes use somewhat fixed multi-channel mechanism. Even in the distributed methods like [20] and [21], the fixed mechanism is needed although it might not best suit current interference environment. This work utilizes the centralized approach, in which the decision on channel allocation is done by the network coordinator based on the collected frequency scanning information from end devices as well as interference detection notification. With such information, suitable decision can be made dynamically in response to the current situation of the network. In order to do so, the system needs to integrate three processes including frequency scanning process, interference detection process, and decision making process. Since an expandable network topology is focused here, the Collection Tree Protocol (CTP) [22] is chosen as a routing protocol. CTP uses routing messages for tree construction and maintenance, and data message to report application data to the sink. Based on the basic mechanism of CTP, the three processes are integrated. Figure 1 shows the flow of our proposed scheme.

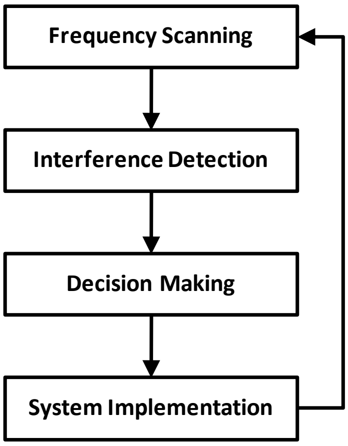


Fig. 1. Process of the proposed scheme.

3.1. Frequency Scanning Process

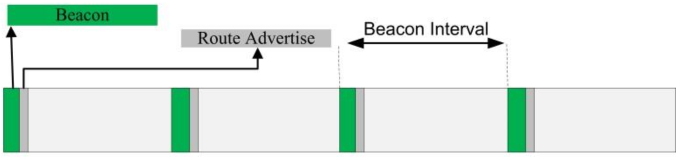
In this process, each end device performs frequency scanning at the fix intervals in order to detect currently available channels, then sends achieved information to the network coordinator. To prove the concept, this work limits the number of channel to be scanned to two channels (although this can easily be enlarged) since in reality channels to be used should have enough separation between or not overlapping with each other. However, number of channel could affect the system performance and this could be considered in the future work. During the scanning process, all devices hop together to different channels with the priory known pattern. The RSSI value (Received Signal Strength Indicator) is used here to determine whether each channel is available or not by comparing obtained RSSI value from the packet transmission with the set threshold.

3.2. Interference Detection Process

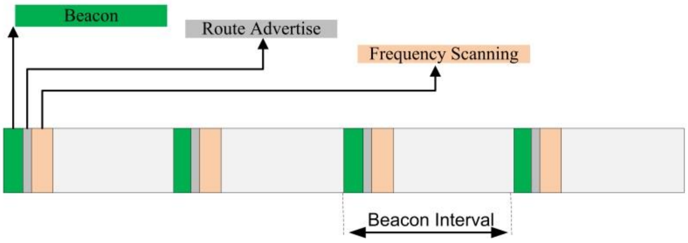
During the system operation, interference detection process is done by observing the number of negative acknowledgement of the beacon frames. If the number of negative acknowledgement is higher than the set threshold, the link is considered being interfered. End device under interference then switches to operate on the second available channel in the list. At the same time, the router (or coordinator in this case) communicating with the interfered end device also detects that the link is broken, hence informing the coordinator as interference is detected. Once the coordinator is informed about the interference, it will use information on the channel availability collected priory and the interference detection notification as part of the decision making to decide on the overall channel allocation.

3.3. Decision Making Process

This process is performed solely by the network coordinator. Using scanning information received with the fixed intervals from end devices as well as interference detection information, coordinator decides on the channel allocation for the entire network i.e. decision whether to switch entire network to a single available channel or to use multiple channels with channel scheduling. The overview of the modified superframe structure is illustrated in Fig. 2. Figure 2(a) shows the typical CTP routing process embedded in the traditional IEEE 802.15.4 superframe structure. Figure 2(b) displays the modified IEEE 802.15.4 superframe structure to support the processes utilized by the proposed scheme.



(a) IEEE 802.15.4 superframe with CTP routing process.



(b) Modified superframe for the proposed centralized control for dynamic channel allocation.

Fig. 2. Superframe structure of the proposed centralized control for dynamic channel allocation.

4. Simulation Model and Test Scenarios

4.1. Simulator

In this section, the developed system-level simulator is illustrated. The simulation model used in this work is created from the basic platform for network simulator called OMNet++ and Castalia, which were designed as simulator for WSNs. This section will give an overview of OMNet++ and Castalia, and then elaborate on the further development done to create the simulation model used in this work in order to test the system performance under various simulation test scenarios.

OMNeT++ [23] is an object-oriented modular discrete event network simulation framework. It has a generic architecture, so it can be used in various problem domains e.g. modeling of wired and wireless communication networks, protocol modeling, modeling of queuing networks, etc. OMNeT++ provides infrastructure and tools for writing simulations. The fundamental components are modules, which communicate through passing message that carries arbitrary data structures. Simple modules are at the lowest level of the module hierarchy and they encapsulate model behavior. Simple modules are programmed in C++.

Castalia [24] is a simulator for WSN, Body Area Networks (BAN) and generally networks of low-power embedded devices. It is based on the OMNeT++ platform and can be used by researchers and developers who want to test their distributed algorithms and/or protocols in realistic wireless channel and radio models, with a realistic node behavior especially relating to access of the radio.

Based on the basic platform of OMNeT++ and Castalia, our simulator is further developed. This includes the integration of all functions introduced in the previous section i.e. frequency scanning function, interference detection function, and simple decision making model. As part of the system modeling, CTP is utilized as it is a well-recognized routing protocol for sensor networks. In general, nodes in these sensor networks collect information about the physical world using their sensors and relay the sensor readings to a central control or network coordinator using multi-hop wireless communication. Collecting information reliably and efficiently from the nodes in a sensor network is a challenging problem, particularly due to the wireless dynamics. Multihop routing in a dynamic wireless environment requires that a protocol can adapt quickly to the changes in the network (agility) while the energy-constrains of sensor networks dictate that such mechanisms not require too much communication among the nodes (efficiency). CTP is a collection tree routing protocol that achieves both agility and efficiency, while offering highly reliable data delivery in sensor networks [22].

CTP is a distance vector routing protocol designed for sensor networks. CTP consists of three main logical software components: the Routing Engine (RE), the Forwarding Engine (FE), and the Link Estimator (LE). The RE is responsible for the sending/receiving of beacons and routing table creation and update. The routing table of each node contains the list of its neighbours along with the ETX (Expected

Transmission) value, which is used to indicate the link quality via such neighbouring node (to the network coordinator). This ETX can be extracted from the beacons as a result of beacon exchange process between neighbours. Node will select its parent (next hop or path to the coordinator) in the routing tree from this table. The ETX of a node is defined as the ETX of its parent plus the ETX of its link to its parent. For each of the node's neighbours, ETX1hop (the link quality of the current node-neighbour link) is computed by the LE. The node then sums up the ETX1hop with the ETX that the corresponding neighbours had declared in their routing beacons. The result of this sum is the ETXmultihop. After the update of all ETXmultihop for all neighbours, node selects the neighbour with the lowest ETXmultihop as its parent (next hop or path towards network coordinator).

FE takes care of the transmission/retransmission of packets to the next hop, decision on when to transmit packets, and the maintenance of the queue of packet to transmit. LE is responsible for the estimation of 1-hop communication links or ETX1hop based on the statistics of number of beacons received and the number of successfully transmitted data packets. Figure 3 shows the overall architecture of traditional CTP.

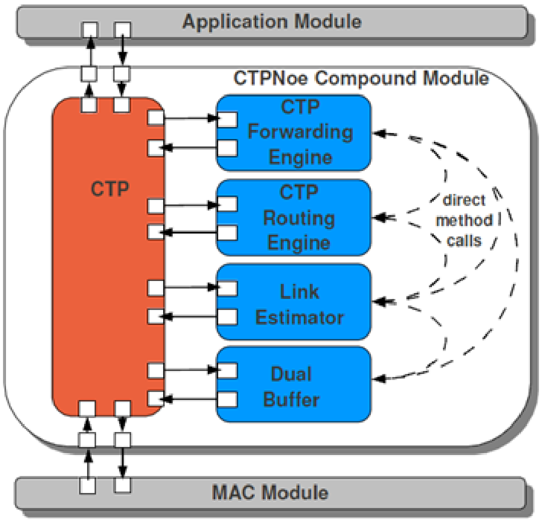


Fig. 3. CTP architecture [22].

4.2. AMCU System Model

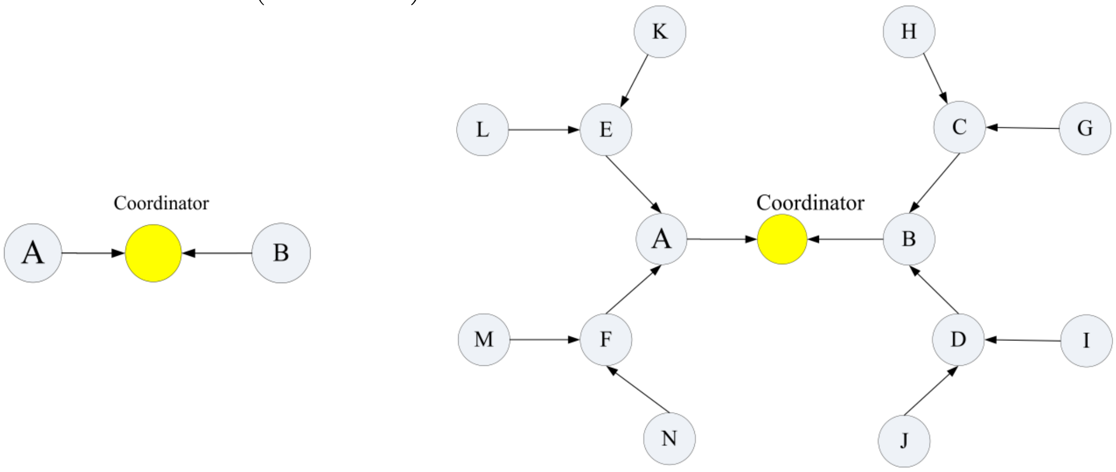
Using the developed simulator as mentioned, simulation has been run for various test scenarios as being illustrated in the next subsection. The system performance is observed for our proposed scheme in comparison with the IEEE 802.15.4 traditional system and the AMCU (Adaptive Multi-Channel Utilization scheme) [4]. This subsection therefore gives a brief introduction to the AMCU scheme.

The main goal of AMCU is to construct a robust WPAN which can be recovered quickly with respect to dynamic, various interference environments as well as beacon conflict. It is assumed that the AMCU consider beacon-enabled mode to conserve limited battery power. In the AMCU, a beacon interval is composed of multiple superframes, and each frame is maintained on different channel, making a repetitive frame hopping pattern. Devices would follow one of the multiple superframes. As a result of using multiple channels dynamically, the authors claimed that an interfered device or coordinator is then capable for quickly avoiding interferences during run time as well as during association stage.

4.3. Test Scenarios

This subsection presents the test scenarios being used in this work. In order to observe performance of the system under our proposed technique, different WSN topologies are created, however with the star or cluster-tree type topologies, which are mainly used for most of the WSN based applications. To cover variety of scenarios in order to see the impact in different cases, the size of the topology and the scale of interference are varied.

There are two test cases based on the size of the network topology implemented here as shown in Fig. 4. Although the proposed scheme can be used in a larger scale and more complicated networks, the two simple scenarios are being tested in order to prove the concept including the small network topology and the large network topology. The small and the large test topologies are depicted in Figs. 4(a) and 4(b), respectively. In both topologies, network coordinator is placed in the middle of each topology and it is receiving data from end devices (sensor nodes).

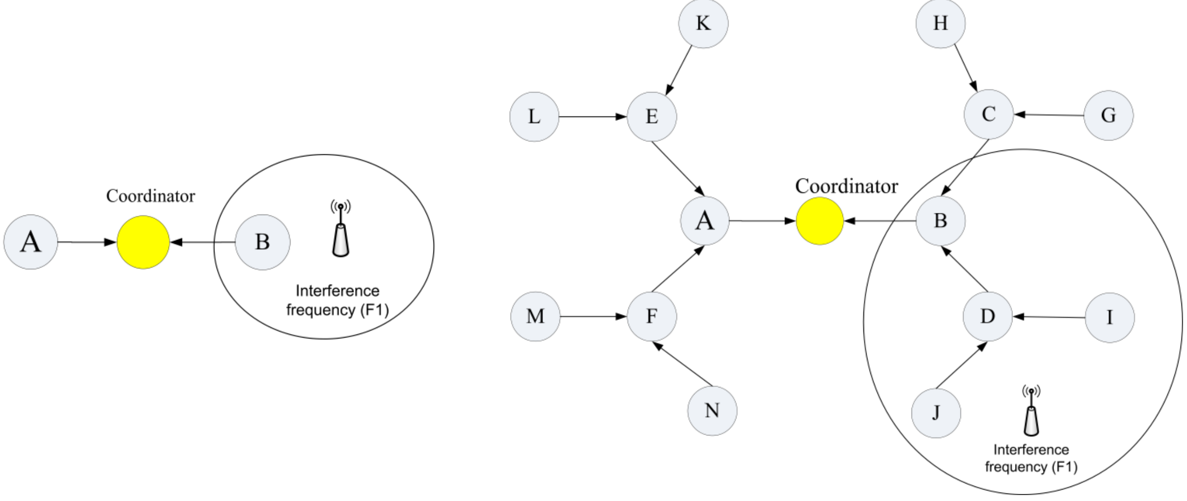


(a) Small topology (b) Large topology

Fig. 4. Simulation—test topologies (no interference test scenario).

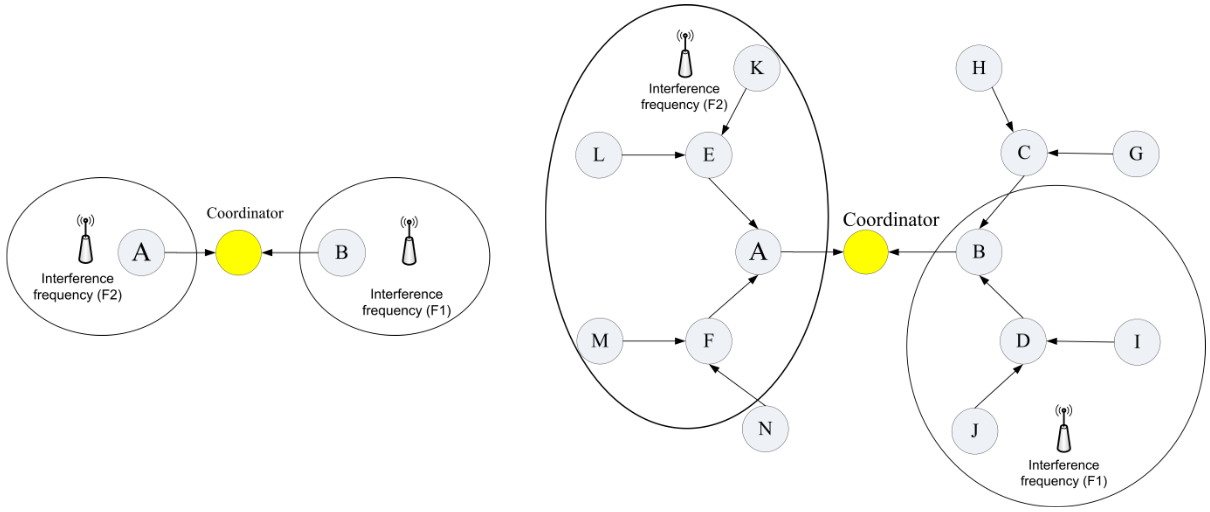
In the first test topology, network consists of a network coordinator and two end devices forming a simple star topology. The network is initially set to operate on a single channel called here as channel F1. This initial channel allocation is the same also for the test scenario based on the large test topology. For the large network topology, it is intended to study larger type sensor networks with cluster-tree type topology, in which part of the sensor nodes need to send data through multiple hops until reach network coordinator.

In order to observe the system performance under variety of scenarios, the level or in this case the scale of interference is varied. For both test topologies, the level of interference being tested includes no interference (as seen in Fig. 4), low interference level (illustrated in Fig. 5) in which interferer only operates on one channel, and high interference (shown in Fig. 6) in which interferers operate on all system's operating channels (the scanned channels).



(a) Small topology—medium interference scenario (b) Large topology—medium interference scenario

Fig. 5. Simulation scenario—medium interference case.



(a) Small topology—high interference scenario (b) Large topology—high interference scenario

Fig. 6. Simulation scenario—high interference case.

5. Simulation Results and Discussion

In this section, the simulation results are presented. The system performance of our proposed method will be compared with the IEEE 802.15.4 traditional system and the AMCU scheme [4]. Simulation results are presented in three subsection including results obtained from no interference scenario, medium interference scenario, and high interference scenario. In each subsection, results will be given for both small network topology and large network topology.

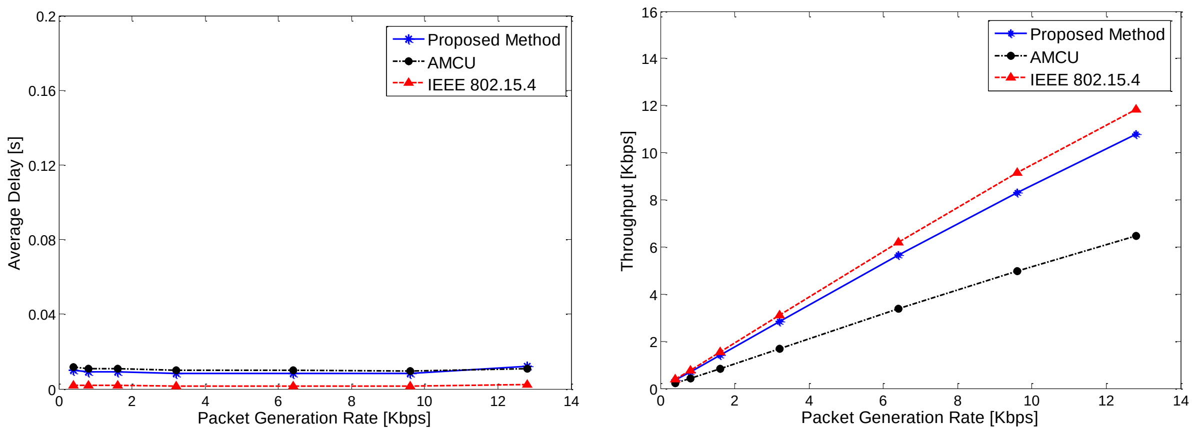
5.1. Simulation for the No Interference Scenario

This section presents simulation results from the no interference scenario, which gives the basic reference case showing general system performance of the system without being interfered. For all the tests, packet generation rate is varied from 0.4 kbps to 12.8 kbps to control the traffic load of the system under evaluation. Results are observed in terms of average packet end-to-end delay and system throughput while traffic load is varied.

5.1.1. Small network topology

Figure 7 shows the simulation results achieved from the no interference test scenario of the small network topology. The plot of average packet delay and system throughput against packet generation rate for the proposed method in comparison with traditional system and system implementing AMCU scheme are shown in Figs. 7(a) and 7(b), respectively.

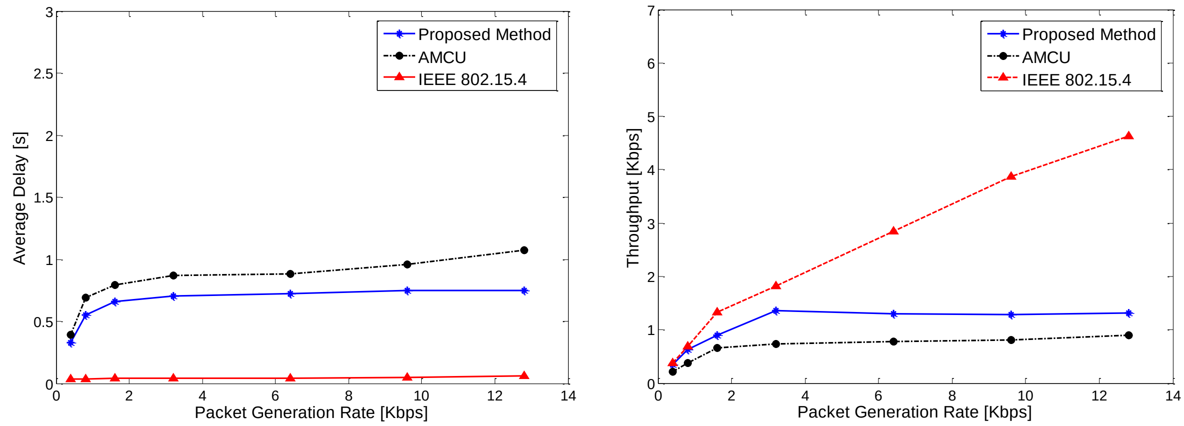
It can be seen in term of average delay that our proposed method, AMCU and traditional IEEE 802.15.4 based system provide rather close delay values and the values are very low. The throughput performance of traditional system is slightly better than our proposed method and also better than that of AMCU. This is due to the low complexity of the system, which always operates on one fixed channel. On the other hand, our proposed method offers slightly lower throughput at high load as a result of signaling overhead for the control purposes. AMCU in this case provides the lowest throughput as it suffers from frequent channel switching even through there is no interference. The higher the packet generation rate, the larger differ in throughput performance between AMCU and the other two approaches.



(a) Average packet delay performance comparison (b) Throughput performance comparison
Fig. 7. Simulation results of small network topology case—no interference scenario.

5.1.2. Large network topology

Similar test scenario is simulated, however this time with large network topology case. Figure 8 illustrates the observed result for average packet delay performance comparison (Fig. 8(a)) as well as throughput performance comparison (Fig. 8(b)).



(a) Average packet delay performance comparison (b) Throughput performance comparison
Fig. 8. Simulation results of large network topology case—no interference scenario.

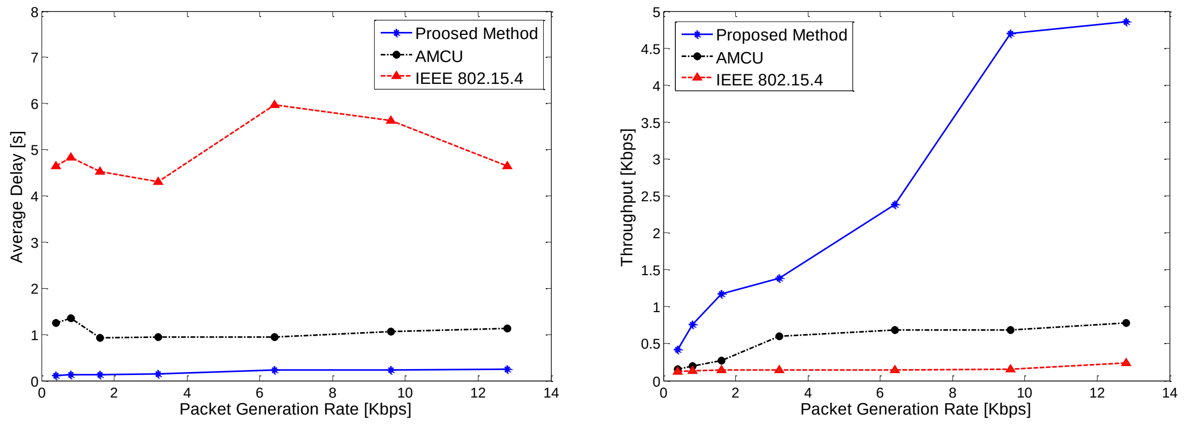
For the large network topology, system performance comparison of the three approaches shows the same trend as for the small network topology, however with higher magnitude for both average packet delay and system throughput. The reason is also the same since traditional system only operates on one fixed channel and no control signaling overhead. In contrast, proposed system needs to slightly compensate the system flexibility with that and AMCU also suffers from frequency hopping.

5.2. Simulation for the Medium Interference Scenario

For the medium interference scenario, interferer is introduced in the overlapping area, which directly affects data transmission in certain part of the network (see Fig. 5).

5.2.1. Small network topology

For the simulation results of small network topology, Figs. 9(a) and 9(b) depict the performance comparison of the three systems in terms of average packet delay and system throughput against packet generation rate, correspondingly.



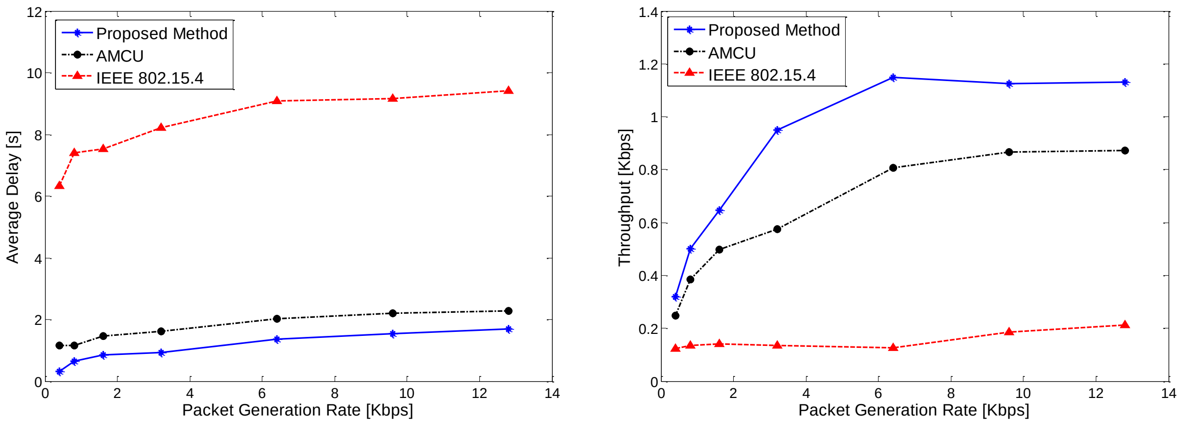
(a) Average packet delay performance comparison (b) Throughput performance comparison

Fig. 9. Simulation results of small network topology case—medium interference scenario.

In term of average delay performance, it can be seen that AMCU and IEEE 802.15.4 offer slightly longer delay and much longer delay than that of our proposed method. The proposed method also offers much better throughput performance than the two systems especially at high traffic load. The performance shows the same trend for the AMCU and traditional IEEE 802.15.4 based system, although slightly better throughput can be achieved from AMCU. Refer to Fig. 5 for the test scenario, part of the sensor nodes is(are) affected by the interference. In the traditional system, this means that such interfered node can barely communicate with other(s), while in the system implementing AMCU the interfered node(s) can communicate only in the periods of non-interfered frequency slots. This significantly reduced the system performance of both networks. On the other hand, our proposed method checks for the network's common available channel and configures the entire network to switch to that new channel allowing communication to continue on a non-interfered channel. As a result, it can maintain best performance in this case.

5.2.2. Large network topology

For the larger network topology under medium interference, Figure 10(a) and 10(b) present simulation results for average packet delay and throughput performance comparison.



(a) Average packet delay performance comparison (b) Throughput performance comparison

Fig. 10. Simulation results of large network topology case—medium interference scenario.

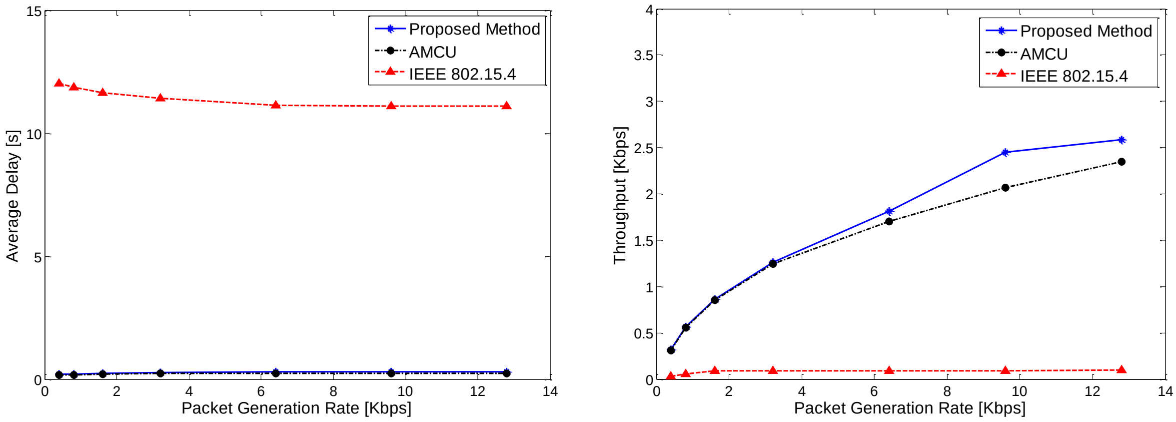
Since the spectrum usage adaptations are the same as in the small topology case, the results show the same trend. However, traditional system achieves much lower throughput with much larger delay than that of our proposed method. The same reason is being that the interfered nodes can hardly communicate with others. As well as for the AMCU scheme, interfered nodes can only communicate during un-interfered time slots.

5.3. Simulation for the high interference scenario

In this simulation. the high interference scenario is implemented in order to observe all systems under severe impact from interferers. Interferers are introduced in several overlapping areas, which directly affects data transmission in certain parts of the network (see Fig. 6).

5.1.1. Small network topology

Simulation results of the small network topology are given in Fig. 11(a) for the average packet delay performance comparison of the three systems and Fig. 11(b) for the system throughput performance comparison of the three systems.



(a) Average packet delay performance comparison (b) Throughput performance comparison

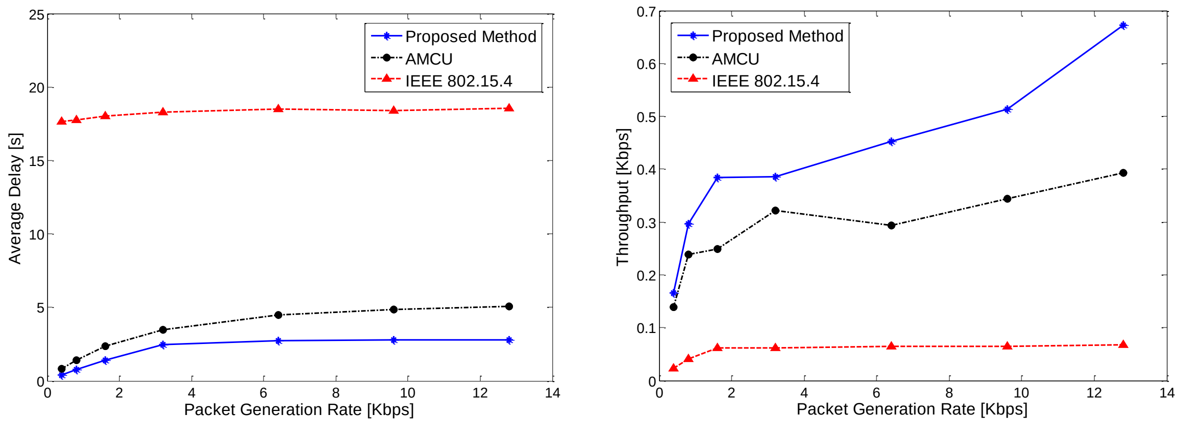
Fig. 11. Simulation results of small network topology case—high interference scenario.

Refer to the test scenario shown in Fig. 6(a), in this test all sensor nodes are affected, however by devices operating on two different channels. One of the channels is the network's currently used channel, F1. Note that in this work, the scanning process performs based on total number of channel of two channels as it is assumed that there is only two channels can be used. This is because the high interference case is aimed at observing the system under severe environment (all possible channels are interfered).

In this case, traditional system is highly interfered. As can be seen, one node is under severe interfere on the currently used channel of F1 and the other node received impact from high power transmission from interfere located in close range although interferer operates on different channel, F2. This therefore results in extremely large delay as well as very low throughput. The proposed system and AMCU provide similar result, since they are both using the scheduling method. In this case, our proposed method also realizes that there is no common available channel, hence deciding to use channel scheduling method. As a result, communication can be done during non-interfered time slots.

5.3.1. Large network topology

For the larger network topology under high interference, Figs. 12(a) and 12(b) present simulation results for average packet delay and throughput performance comparison.



(a) Average packet delay performance comparison (b) Throughput performance comparison

Fig. 12. Simulation results of large network topology case—high interference scenario.

The general conclusion gained from this scenario is that the results show similar trend as that obtained from small and large network topology, however with high magnitudes for packet delay performance and with lower ranges for throughput performance for the large topology. This is due to the scale of the network topology.

In summary, with any degrees of interference, our proposed method offers either much better or similar service performance than the system implementing AMCU approach. In comparison with traditional system, without interference traditional system may perform slightly better, however with any scales of interference, our proposed method by far outperforms the traditional system.

6. Conclusion

In this work, the centralized control for dynamic channel allocation in IEEE 802.15.4 based WSNs is presented. Coexistence issue between IEEE 802.15.4 based ZigBee and interference caused by other devices operating on the overlapping channels are studied and the effects are investigated. The proposed method employs the central control for decision making process in order to allow flexible and suitable multi-channel allocation in respond to current system environment. System performance is evaluated using the developed system-level simulator. The simulation results show that our proposed method provides much better system performance in terms of throughput and packet delay under any scale of interference environment than the traditional IEEE802.15.4 system. It can also be concluded that the proposed system is more flexible than the method based on fixed mechanism like the AMCU. Although in some scenarios the performance are similar, the proposed system highly benefits from being able to deviate from fixed channel scheduling to the better overall solution leading to better system performance in such scenarios.

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