



## Multichannel Communication – A Need for Wireless Sensor Networks

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**Abstract -** Improvements in wireless sensor network (WSN) technology have resulted in a large number of applications. WSNs are used to target tracking, monitoring applications, and health care. In WSN nodes are generally deployed in harsh environmental conditions where the batteries of sensor nodes are difficult to charge or replace. The main goal of communication protocols in WSNs is to maximize energy efficiency in order to increase the network lifetime. Today, many radio chips of sensor hardware can work at different frequencies. There are many multichannel communication protocols have been proposed to reduce packet loss and improve network throughput of sensor networks. we have observed that multichannel communication protocols are more preferred over single channel protocols, where one want to achieve more throughput, less delay, efficient energy communication, especially in case of multimedia data transmissions. Single channel schemes are not well suited due to the fact that they share all the information using one channel. The design of multi-channel MAC protocols has attracted the interest of many researchers as a cost effective solution to meet the higher bandwidth demand for the limited bandwidth in WSNs and WMSNs (Wireless Multimedia Sensor Networks). In this paper, we have focused on multichannel communication in wireless ad hoc networks and WSNs with its benefits. This paper also describes channel schemes for MAC (Media Access Control) protocols and challenges for multichannel MAC protocols in WSN.

**Keywords:** WSN, Multichannel, MAC

### I. INTRODUCTION

In recent years, there is lot of advancement in the digital electronics, micro-electro-mechanical systems (MEMS) technology and wireless communications. This advancement in the technology has started the development of less expensive and low-power sensor nodes with multiple functionalities. These sensor nodes communicate in short distances and are very small in size. These sensor nodes consist of components for sensing, data processing, and communicating. The block diagram of a wireless sensing node is shown in Figure 1. The signal conditioning block can be reprogrammed or replaced based on the sensors deployed. Similarly, the radio link may be swapped out as needed by a given application, depending on wireless range requirements and the need for bidirectional communications. The microcontroller was programmed to operate in a mode which automatically pulses power to the sensing portions of the electronics, while synchronously performing analog to digital conversions and RF communications [22].

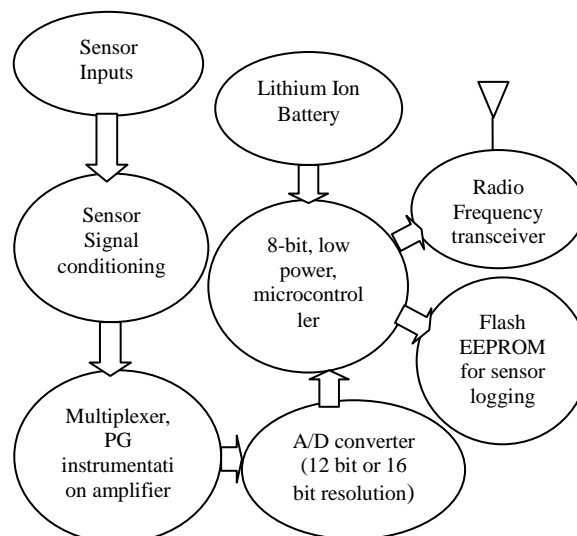


Figure 1. Wireless Sensor Node

A sensor network contains a large number of sensors, which are deployed densely. Mostly, there is no need to pre-

determine the position of sensor nodes. Sensors can be randomly deployed in the terrains which are inaccessible by humans or disaster relief operations.

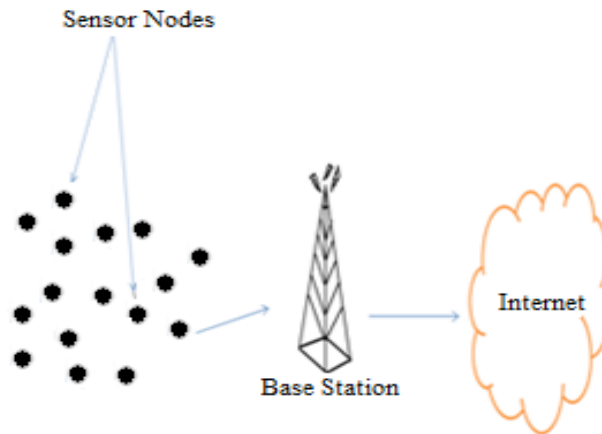


Figure 2. Wireless Sensor Network

Due to the randomness in the sensors deployments, protocols and algorithms for sensor network must have self-organizing capabilities. One important feature of wireless sensor networks is the cooperative work of sensors for transmitting data to base station. Sensor nodes do not transmit raw data directly to the central node. Sensors contain an on-board processor; they perform simple computations locally by using their processing capabilities. Only the required and partially processed data is retransmitted. Limited bandwidth is an important issue for WSN. In multi-hop wireless sensor networks bandwidth is a critical issue, because of interference between successive hops on the same path as well as that between neighbouring paths. WSNs uses Radio transceivers for communication and these are typically less expensive devices. These Radio transceivers offer low bandwidth communication only. When spontaneous communication occurs in many sensor nodes which are triggered by physical events in the real world, causes heavy load problem in single channel. Therefore, many messages are dropped due to collisions. Since CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance) schemes are well suited to spontaneous communication, but due to heavy load these schemes do not provide high channel utilization. For these Problems, the another cost effective solution is to use multiple channels that works for parallel data transmission based on the current WSN hardware, such as MICAz and Telosb that provide multiple channels with single radio. A number of multi-channel MAC protocols have been implemented for general wireless networks with single radio [15]. MAC protocols for general wireless networks are designed using 3-way handshake or RTS/CTS techniques for channel/time negotiation. It produce a significant control overhead for resource constrained sensor nodes because of small MAC layer packet size in WSN compared to general wireless networks. Hence, multi-channel MAC protocol for WSN and MWSN should consider the minimum control overhead possible in negotiating the time/channel selection. As performance degradation in traditional single channel protocol, several multi-channel communication protocols have been proposed to improve network throughput for WSNs.

This paper is follows as: Chapter I represents the Introduction of WSNs. Chapter II represents the channel schemes. Chapter III represents multichannel Communication in Wireless Adhoc Networks. Chapter IV represents multichannel communication in Wireless sensor networks. The last section represents the conclusion and references.

## II. CHANNEL SCHEMES

This section will explain about the hidden and exposed terminal problems and single channel and multichannel approaches.

### *Hidden and Exposed terminal problems*

Hidden and exposed terminal problems have become a major issue in MANET [18]. The two scenarios below will illustrate how they cause problems in Mobile Ad hoc networks. In figure 3(a), Node B is transmitting to Node A and Node C wants to transmit to Node D. Since Node C can sense Node B, it will not transmit though it can send without causing problem. Here bandwidth waste (less spatial reuse) becomes an important issue and Node C will starve from transmission while its window size increases.

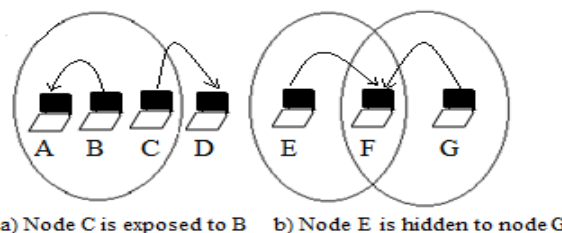


Figure 3. (a) Exposed terminal problem (b) Hidden terminal problem

This scenario is known as exposed terminal problem. The Figure 3(b) illustrate that when Node E is trying to send to Node F, and meanwhile Node G which is out of the transmission range of Node E, is trying to transmit to Node F as well. Hence, a collision will occur at the receiver (Node F). This is known as “hidden terminal problem” which significantly decreases the throughput.

#### *A. Single channel schemes*

Single channel schemes are used to share all the information (e.g. control signals and the DATA), using one channel. But these schemes faced a lot of problems that decreased the entire network throughput [18]. IEEE 802.11 DCF is one of the most famous protocols that use single channel to run on MANET [18]. It is not being efficient in multi-hop ad hoc networks due the hidden and exposed terminal problems. Multiple Access with Collision Avoidance (MACA) did not use the carrier sensing option and instead, it used the RTS/CTS/DATA handshake to reserve and use the channel. Although this protocol was a simple design, the control channel collisions made the scheme not effective in the MAC layer.

#### *B. Multichannel schemes*

The hidden and exposed terminal problems are one of the most important issues here that single channel schemes were not able to eliminate though they slightly alleviated them. The ad hoc nodes and sensor nodes are battery operated. The way of consuming energy and the amount of power being saved is an important issue in these networks. The power option comes with the protocol so that the nodes save their energy while transmitting and therefore, improve the network efficiency. DCA-PC (Dynamic channel assignment with power control) uses one channel for control signals and N channels for data transmission [18]. The channels are allocated dynamically using an RTS signal where the receiver will pick the selected channel and will use CTS signal to send information. Each host has two transceivers for listening to both the channels simultaneously. DCA-PC solves the hidden terminal problem since one of the transceivers always listen on the signalling channel. It uses Power control schemes, where the control packets are transmitted with a maximum power and the data packets are transmitted using the required amount of power. Therefore, the power is being saved while avoiding the hidden terminal problem.

##### *B.I. Benefits of Using Multiple Channels*

In single channel networks with heavy traffic, sensor nodes may suffer from a large number of collisions, interference, low delivery ratio, and long delivery latency. There are two benefits of using Multiple Channels:

- Multiple channels can increase the available network capacity.
- Multiple channels can receive and transmit data in parallel.
- In multi-channel communication, a node can transmit and receive data under less interference and collisions.

Multi-channel protocols can be categorised into three ways:

##### *a. Improve network throughput*

Wu et al. proposed the TMCP multi-channel tree collection protocol and examined the network throughput doubled as the number of available channels increased from two to eight [11]. Zhang et al. proposed the TMMAC MAC protocol and conclude that it achieved seven times the throughput of the standard 802.11 DCF protocol on a simulated network with 40 concurrent flows when six channels were available [5]. TMMAC avoids contention based communication during the communication window. Contention based communication adopted by 802.11 DCF wastes some bandwidth in backoff, and sending RTS and CTS control packets. Besides, TMMAC is able to dynamically adjust the ATIM (Ad Hoc Traffic Indication Messages) window size, which further improves throughput.

##### *b. Minimize intra-network interference*

Due to concurrent transmission in the same broadcast manner, it could lead collisions and possibly packet losses. Wu et al. presented empirical results suggesting that 802.15.4 radios have a maximum of eight orthogonal channels. To reduce the number of conflicting transmissions, Zhou et al. [2] and Liang et al. [8] used channel diversity and also observed that channel diversity promotes spatial reuse. This reduces the latency of network wide dissemination.

##### *c. Avoid external interference*

Supposing that multiple radio standards (802.11, 802.15.4) all operate in same unlicensed frequency bands i.e. 2.4GHz band, the channel diversity is one solution to mitigate external interference among collocated WSNs. The Wireless HART standard offers an example of this approach [9]. It uses a TDMA protocol, in which sensor nodes switch their radio frequency at the beginning of each time slot. The frequency is selected by current time slot index and a secret channel offset shared by the two communicating nodes.

### **III. MULTI-CHANNEL COMMUNICATION IN WIRELESS AD HOC NETWORKS**

Wireless ad hoc network is an infrastructure less network. It means that it is a collection of wireless devices that self-configure to form a network without the aid of any established infrastructure [3]. WSNs are sub-class of wireless ad hoc networks and the studies related to multi-channel communication in wireless ad hoc networks can provide guidance in designing protocols for WSNs.

#### *A. Single-Radio Multi-Channel Wireless Ad Hoc Networks*

This can be classified the protocols according to the channel assignment methods [14]:

##### *A.I. Fixed assignment*

Radios are assigned channels for permanent use and can be renewed. The basic idea is to cluster the nodes into different frequencies such that each cluster only uses a single channel which is different from the channels that are assigned to the clusters which may cause interference.

##### *Advantages:*

- Ease of implementation since the dynamics due to channel switching and variations in the network topology are not considered.

##### *Disadvantages:*

The fixed channel assignment causes the following problems by enforcing the nodes to keep their interfaces on a particular channel:

- Due to unstable links, Network conditions may change over time.
- During a channel assignment, it is required to examine those nodes that need to communicate with each other. Alternatively, the channel assignments need to be renewed frequently due to changing requirements in the network.

##### *A.II. Semi-dynamic assignment*

Radios are assigned constant channels, either for receiving or transmitting with the possibility of changing channel for communicating with the radios. To solve the channel assignment problem, the graph –based approach is used, in which vertices represents the nodes and the edges represent the communication links. In case of parallel communication edges, Interference links can also be included [21]. This method can benefit from the extensive research on graph colouring algorithms.

##### *Advantages:*

- Nodes can switch to the different channels to communicate with different neighbours for eliminating the network partitions.

##### *Disadvantages:*

The problems that arise due to the channel switching are listed as follows:

- *Multi-channel hidden terminal problem:* This problem arises by nodes that miss the control packets, start transmission of control packets on the destination's channel which leads collision.
- *Deafness problem:* After sending the multiple requests when a transmitter does not get any response and may conclude that the receiver is not reachable anymore, then this problem occurs. It is related with the RTS/CTS based protocols.
- *Broadcast support:* When the nodes are switching between channels dynamically, it might be problematic to support broadcasts.

##### *A.III. Dynamic assignment*

Nodes can dynamically switch their interfaces from one channel to another between successive data transmission. These approaches share many problems of semi-dynamic channel assignment such that multichannel hidden terminal, deafness and broadcast support.

Dynamic channel assignment is categorized into three ways based on the methods of coordination:

##### *a. Dedicated Control Channel*

Nodes are synchronized by exchanging control packets on this channel. With this Approach, nodes negotiate for the channel to be used for data exchanges.

##### *Advantages:*

- There is no need of time synchronization.
- Dedicated control channels are easy to implement.

##### *Disadvantages:*

- This Approach causes the control channel bottleneck problem because the control channel can only be used for exchanging control messages and data exchange proceeds over the data channels.

##### *b. Split Phase*

Nodes acquire the medium in two phases:

- In control phase: all nodes switch to a common control channel. There is a contention based access mechanism to the medium and different protocols are supported according to the channel access mechanisms.
- Data exchange phase: Nodes negotiate with their intended receivers for the channels that are to be used.

An example of contention based protocols is Multi-Channel MAC (MMAC). Multi Channel Access Protocol (MAP) and TMMAC are examples of protocols that are based on scheduled access.

##### *Advantages:*

- Elimination of multi-channel hidden terminal and deafness problems.

*Disadvantages:*

- Need of time synchronization and during the control phase the non-control channels remain idle.
- Channel switching time may affect the performance depending on the hardware used.

*c. Frequency Hopping*

This approach uses node hop mechanisms between different channels. Two variations are explained as:

- *Common hopping:* If nodes agree to exchange the data packets and rejoin the hopping sequence after the transmission, all nodes hop according to the same patterns and also remain in the same channel.
- *Independent hopping:* Nodes don't depend on the other nodes' hopping sequence. They generally follow their own hopping sequence which enables the exchange of hopping sequences. McMAC and Slotted Seeded Channel Hopping (SSCH) are examples of independent hopping.

*Advantages:*

- Eliminate the channel negotiation process. Nodes simply follow their hopping pattern in order to exchange packets.

*Disadvantages:*

- In this approach, there is need of tight time synchronization and
- Channel switching time is an important overhead.
- Limited memory of nodes and keeping the hopping sequence of each neighbour causes extra overhead.

*B. Multi-Radio Multi-Channel Wireless Ad Hoc Networks*

This section describes the multi-radio multi-channel networks. As compared to single radio variant with multi radio multichannel wireless adhoc networks, coordination of communication is very simpler in multi-radio multi-channel wireless adhoc networks. Based on channel assignment approaches, the multi-radio multi-channel wireless adhoc networks are categorized as [10]:

*B.I. Fixed Channel Assignment*

Fixed Channel Assignment works similar to semi-dynamic channel assignment for single radio networks and assign a permanent channel to each radio. The assignment of channel follows the graph based approaches. For example, assignment of channel is formulated as a topology control problem to minimize the link conflicts and still keeping the connectivity of the network [14].

*Advantages:*

- Provide easier solution to the problem since the conditions are not considered dynamic. In this approach, Graph-colouring methods can be used to solve the channel assignment. As there are multiple radios, the connectivity problem is easily solved compared to the single-radio wireless ad hoc networks.

*Disadvantages:*

- The fixed assignment cannot adapt the use of channels according to the varying conditions such as interference, load, etc.

*B.II. Semi-Dynamic Channel Assignment*

This method also assigns fixed channels to the radios. However, according to changing conditions channel assignment is repeated periodically.

*Advantages:*

- The advantage of semi-dynamic channel assignment over the fixed channel assignment is that most of the algorithms are load-aware which means that the data rates over links are considered to be dynamic.
- Load-aware channel assignment enhances the performance when the nodes transmit with variable data rates.

*Disadvantages:*

- Dynamic traffic patterns estimation may be quite challenging.
- Depending on the level of interference external interference-aware assignment can change the channel use which is an important property considering the intensive use of the ISM (Industrial Scientific and Medical) bands.

*B.III. Dynamic Channel Assignment*

A number of multi-radio multi-channel wireless ad hoc network protocols favour to keep some of the interfaces fixed while some of the interfaces switch over different channels to keep the network connected.

*B.IV. Hybrid Channel Assignment*

In this method, some interfaces are allocated fixed channels whereas others switch between different frequencies. It has the advantage of preserving the connectivity of the network. Simultaneous transmissions can be performed while the channel switching delay is avoided.

## **IV. MULTI-CHANNEL COMMUNICATION IN WSNs**

In this section we have given the channel assignment techniques for WSNs and main differences between multi-channel communication in WSNs and wireless ad hoc networks. WSNs are defined as a sub-class of wireless ad hoc networks

[14]. However, generally wireless ad hoc networks consist of personal digital assistants (PDA), palmtops, laptop computers etc. with more complex radios. The wireless ad hoc networks protocols such as IEEE 802.11 are costly in terms of energy consumption for the resource constrained sensor nodes.

#### *A. Differences between multi-channel communication in WSNs and Wireless ad hoc networks*

The algorithms and protocols proposed for traditional wireless ad hoc networks are not well suited for the wireless sensor networks due to their unique features and application requirements. To illustrate this point, the differences between sensor networks and ad hoc networks are mentioned below:

- Sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications.
- The number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
- Sensor nodes are equipped with simple radios and usually a single radio is available at each node.
- Sensor nodes are densely deployed than the nodes in a wireless ad hoc network.
- Bandwidth is limited on sensor radios, e.g. 50kbps, whereas the nodes in a wireless ad hoc network can transmit with much higher rates.
- Sensor nodes are prone to failures.
- Most of the channel assignment protocols in wireless ad hoc networks are based on a variant of the IEEE 802.11 protocol which cannot be supported by the simple radios of the WSN devices.
- The topology of a sensor network changes very frequently.
- Sensor nodes are limited in power, computational capacities, and memory. WSNs have tighter requirements on the lifetime and replacing or recharging the batteries may not be always possible. On the other hand, in other wireless ad hoc networks, a terminal can be fairly powerful such as a PDA or a laptop
- Sensor nodes may not have global identification (ID) because of the large amount of overhead and large number of sensors.

Therefore, based on these differences multi-channel protocols developed for wireless ad hoc networks may not be directly applied to WSNs since the traditional requirements of WSNs, such as energy-efficiency and scalability, remain important concerns. Multi-channel communication can be used to overcome the congestion which occurs due to interference and contention in the network.

#### *B. Channel assignment techniques in WSNs*

As in wireless ad hoc networks, these are similarly classified as:

##### *B.I. Fixed Channel Assignment*

In fixed channel assignment, the nodes are clustered into different frequencies. The IEEE 802.15.4 standard also uses fixed channel assignment but it is possible that the beacon node can change the operating frequency of its network if the nodes report excessive levels of interference. The examples are presented in [3, 11]. In [11], it is discussed that there may be potential packet losses due to frequent channel switching.

##### *B.II. Semi-Dynamic Channel Assignment*

In semi-dynamic approaches nodes are assigned fixed channels but they can switch between channels in order to communicate with other nodes. In the study, it is found that may cause potential packet losses increases because of very frequent channel switching. Examples are presented in [2, 6, 12].

##### *B.III. Dynamic Channel Assignment*

Y-MAC is the first example that uses dynamic channel assignment in WSNs [7]. In this method, combination of a dedicated control channel and a frequency hopping method is used. Y-MAC is based on scheduled access. Time slots are assigned to the receivers instead of senders. At the starting of each time slot, potential senders for the same receiver contend for the medium. The length of each time slot is enough to transmit one data packet. When there is a need to transmit multiple packets, then the sender and the receiver hop to a new channel according to a predetermined sequence. Other potential senders also follow the hopping sequence of the receiver.

There is a full utilization of orthogonal channels by nodes in case of semi dynamic and dynamic approaches. Each node in the dynamic approach switches its channel in every wakeup schedule [20]. There is longer end-to-end delay and more energy consumption due to large number of channel switching, because a radio chip needs time and energy for channel switching. Radio chip cannot transmit or receive data during channel switching whereas, in semi-dynamic approach, there is a less channel switching because channel switching is done only for communication.

#### *C. Challenges for multichannel MAC protocols*

In Multi-channel communication throughput of network can be improved by allowing parallel transmissions. But, for successful transmission of data, both nodes should be connected on same channel in the same time. It is complicated to design an efficient multi-channel MAC protocol, since, besides standard single-channel MAC related problems; there are some multi-channel-related problems as discussed below:

C.I. Multi-channel hidden terminal problem

This problem occurs when a node Z is busy in transmitting or receiving on a data channel, then a neighbouring node X initiates a channel reservation handshake on the control channel [19]. Because the node Z is active on a data channel, it is unable to realize its neighbouring selected channel and may inadvertently choose the same channel when it starts its next data exchange. Therefore, some protocols assign different available physical frequencies within two interference hops to avoid this problem.

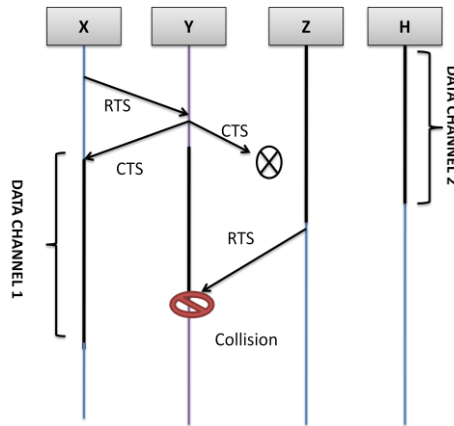


Figure 4: Multichannel hidden terminal problem

C.II. Multi-channel missing terminal problem

When a transmitter wants to send a packet to a receiver and if its transceiver happens to be tuned to another channel, the missing receiver problem occurs.

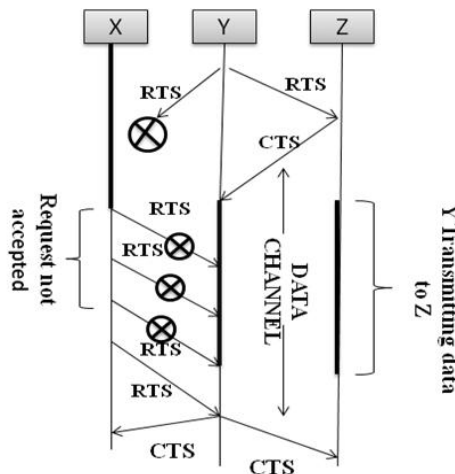


Figure 5: Multi-channel missing terminal problem

In the missing receiver problem as shown in Figure 5, node X tries to communicate with node Y by sending the RTS packet, while Y is busy in data transfer on a different channel [19].

C.III. Broadcast support problem

In single channel, mainly broadcast packet can be heard by all neighbouring nodes. But in multi-channel mode different nodes are assigned a different channel for packet reception, some nodes may miss the broadcast messages.

C.IV. Channel allocation problem

In multichannel communication packet transfer is feasible only if both, transmitter and receiver are tuned at the same channel. Therefore, an efficient channel allocation technique should be used in multichannel MAC protocol. Channels must be evenly distributed by using efficient channel allocation technique among nodes and has capability of overcoming hidden terminal problem.

C.V. Channel switching time problem

A certain amount of time is needed for channel switching in Radio transceiver (e.g. 300 μs with CC2420 [4]). During this time, receiving and sending are unable; therefore, frequent channel switching causes increase in delay and decrease in

throughput. In WSNs, Channel switching time problem is critical when the time for transmitting a message is nearly as short as the time required for channel switching. There is loss of time as well as energy due to frequent channel switching.

#### *C.VI. Number of channels problem*

There is a great impact of adjacent channel interferences on radio reception, so cannot be neglected. This problem causes unexpected collisions which leads to loss of packets. For example, radio transceiver CC2420 [4] provides 16 different working channels in 2.4 GHz frequent range. All channels cannot be used, due to channel overlapping, which could lead to interference.

#### *C.VII. Synchronization*

Synchronization is much needed in dynamical channel allocation as nodes can switch among different channels. It means transmitter and receiver must be on the same channel. The same problem does not exist in multi-channel MAC protocol when fixed channel allocation technique is used.

#### *C.VIII. Network Partitioning*

In network partitioning, neighbouring nodes cannot communicate, if they are on different channels. This phenomenon is known as network partitioning. Therefore, in order to assign same channel for nodes, it is necessary to know in advance which nodes want to communicate. In order to adapt network changes channel allocation should be repeated periodically.

#### *C.IX. Joining to the network*

When a new node joins the network it randomly chooses the channel, hence, it could disrupt channel organization in its neighbourhood. One possible solution could be that node first listen all channels for the certain amount of time, in order to choose free channel for emitting.

## **V. CONCLUSION**

In this paper we have presented multichannel communication its benefits and challenges for ad hoc networks and WSNs. In single-channel wireless networks, it is difficult to remove contention and collisions because each node in wireless networks shares the wireless medium with its adjacent nodes. In single-channel communication, network throughput and capacity are limited as it uses only one channel. In networks with heavy traffic, sensor nodes may suffer from a large number of collisions, interference, low delivery ratio, and long delivery latency. Whereas, a multi-channel radio generates several orthogonal channels from an available frequency. Adjacent nodes can transmit their packets at the same time through different channels because these channels do not interfere with each other. Therefore, multichannel protocols not only improve network throughput and capacity, but also reduce collisions and interference. The single channel MAC protocols that aim to provide high throughput function well in single channel scenarios, but parallel transmissions over multiple channels can further improve the throughput by eliminating contention and interference on a single channel. The use of multiple channels for transmission of multimedia data over WSNs, leads to improve the throughput and energy efficiency of the MAC protocols for wireless sensor networks. However, the design of a multichannel MAC protocol depends on requirements of the actual application, regarding energy efficiency, throughput and delay, since no specific medium access scheme provides best performances over all traffic condition and network densities. Therefore, multichannel communication proves better choice for WSN MAC protocols and also supports multimedia data transmission over wireless sensor networks.

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