# A Survey on MAC Protocols for Wireless Sensor Networks and Cognitive Radio Sensor networks Design

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**Abstract**

Wireless Sensor Networks (WSNs) has been a wide research topic for more than a decade. Typically, a WSN consists of spatially distributed autonomous sensors to monitor physical or environmental conditions. These sensors generate report over the network on the occurrence of any event. For a WSN to provide better reliability and improved lifetime, an efficient Medium Access Control (MAC) protocol design holds a paramount importance. Several multi-channel MAC protocols exist which performs better than the single channel protocols. The MAC layer coordinates transmission between the users sharing a spectrum and improves the throughput and energy efficiency. *Cognitive Radio* (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and make those channels available for concurrent transmissions. Dynamic spectrum access in the form of cognitive radio provides spectrum efficient communication for all WSNs which led to the development of Cognitive Radio Sensor Networks (CRSNs). This paper highlights an intensive survey of MAC protocols defined for WSNs and the design of Cognitive Radio based WSNs.

***Keywords—Wireless Sensor Networks (WSNs), Medium Access Control (MAC), Cognitive Radio (CR)***

## 1. Introduction

Wireless Sensor Networks (WSNs) deliver smart communication paradigm which can set up intelligent networks handling all the applications as per the user requirements. The WSNs offer several advantages like flexibility, fault tolerance, low cost and easy deployment. These advantages enable exciting applications of WSNs in the field of military,environment monitoring,health, surveillance, industry, smart buildings, medical care and home applications.

The WSNs provide data transmissions with guaranteed quality of service (QOS) in every application. A key issue in WSNs is the energy-constrained nature of sensor nodes on which researchers have been working for so many years to improve throughput, lifetime, data-rate and hence the overall network performance. Most WSNs are expected to suffer severe interference by other networks sharing the same spectrum in license-free band. Therefore achieving QOS in such networks seems to be very difficult.

A Medium Access Control Protocol (MAC) holds an inevitable support for WSNs in this scenario. The MAC refers to a technique which can provide successful operation of networks. One major task of the MAC protocol is collision avoidance by restricting simultaneous transmissions between nodes. Many MAC protocols have been developed for the smart performance of WSNs. The design of a good MAC protocol gives prime consideration for energy efficiency, scalability, throughput, latency, fairness and bandwidth utilization. An efficient MAC protocol should be adaptable to the network changes that can happen like changes in topology, network size and node density.

Both single channel and multi-channel MAC protocols have been developed for WSNs which provide efficient data transmission. However the multi-channel schemes perform better than the single-channel MAC protocols when analyzed for communication performance and energy consumption. The single channel protocols cannot work well in multi-channel environment and so many multi-channel MAC protocols have been proposed which assign multiple channels to the nodes. This enables simultaneous data transmissions over multiple communication links and hence the network performance is improved.

The idea for Cognitive Radio (CR) has come out of the need to utilize the radio spectrum more efficiently, and to be able to maintain the most efficient form of communication for the prevailing conditions. The term "Cognition" refers to the process of knowing through perception, reasoning, knowledge and intuition with a focus on information available from the environment [6].Cognitive communication over WSNs could meet the end-to-end goals of a network while increasing the reliability and lifetime of a network and reducing the maintenance costs. The CR technology could provide access not only to new spectrum, but also to spectrum with better propagation characteristics [8]. The use of CR networks (CRNs) in WSNs has led to the emergence of Cognitive Radio Sensor Networks (CRSNs).The CR reduces congestion and excessive packet loss and thereby makes the transmission more reliable.

The remaining part of this paper is organized as follows: Section II describes various MAC protocols proposed for WSNs. Section III presents the conceptual design of CRSNs. Finally, Section IV concludes the paper.

## 2. MEDIUM ACCESS CONTROL (MAC) PROTOCOLS FOR WIRELESS SENSOR NETWORKS (WSNs)

The MAC protocol improves energy efficiency in wireless communicating sensor networks by increasing sleep duration and decreasing all the sources of energy wastage. The major sources of energy waste are collision, overhearing, control packet overhead and idle listening. A MAC protocol reduces the waste of energy from all these sources. The functions of a good MAC protocol include framing, medium access, reliability, flow control and error control. Several MAC schemes have been proposed over the years to improve the overall performance of WSNs. These MAC protocols can be broadly classified as schedule based and Contention based schemes.The schedule based protocols involve time synchronization requirements but the contention based protocols relax time synchronization requirements. All these MAC protocols consist of acknowledgement (ACK) messages and retransmissions through which better reliability can be achieved. Although traditional MAC protocols achieve low-power operation, they use only a single channel which limits their performance [4]. Therefore several multi -channel MAC protocols for WSNs have been recently proposed [4].Hence a high quality MAC design provides an efficient utilization of limited amount of energy as its primary concern.

### 2.1 SENSOR-MAC (S-MAC) PROTOCOL

The Sensor-Media Access Control (S-MAC) is a contention based MAC protocol explicitly designed for wireless sensor networks. While reducing energy consumption is the primary goal in this design, the protocol also has good scalability and collision avoidance capability [1]. A combined scheduling and contention scheme is utilized in this protocol which helps in achieving good scalability and collision avoidance. The S-MAC applies message passing to reduce the contention latency for sensor-network applications that require store-and-forward processing as data move through the network [1]. Energy consumption is reduced and self-configuration is supported by three novel techniques in S-MAC. The energy waste is reduced to a great extent in S-MAC design. Here the time frame is divided as a listening session and a sleeping session. In SMAC, the sensor nodes communicate with additional nodes by sending some control packets such as SYNC, RTS (Request to Send), CTS (Clear to Send) and ACK (Acknowledgement) during listen period. A SYNC packet exchange can synchronize all the nearest nodes collectively. Then the RTS/CTS switch is used over the two nodes that needs to communicate with each other.

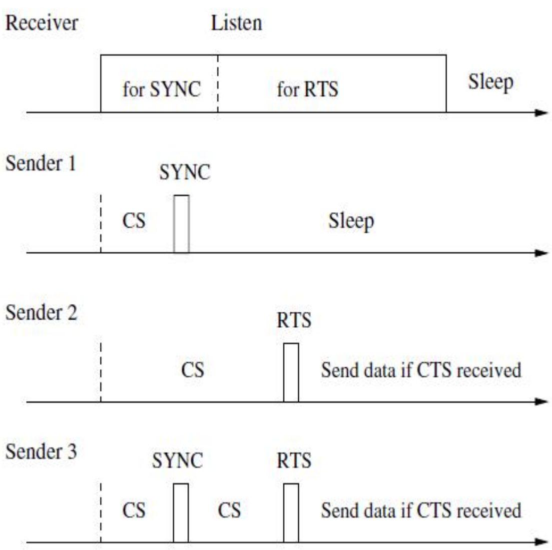


Fig 1: Timing relationship between a receiver and different senders, CS stands for carrier sense [1]

## 2.2 BERKELEY MAC (B-MAC) PROTOCOL

Another contention based MAC protocol extensively used in WSNs is the Berkeley Media Access Control (B-MAC) protocol. This scheme provides a flexible interface to obtain ultra low power operation, effective collision avoidance and high channel utilization [2]. An adaptive preamble sampling scheme is employed in B-MAC to achieve low power operation, reduced duty cycle and minimized idle listening. B-MAC supports on-the-fly reconfiguration and provides bidirectional interfaces for system services to optimize performance, whether it be for throughput, latency, or power conservation [2].

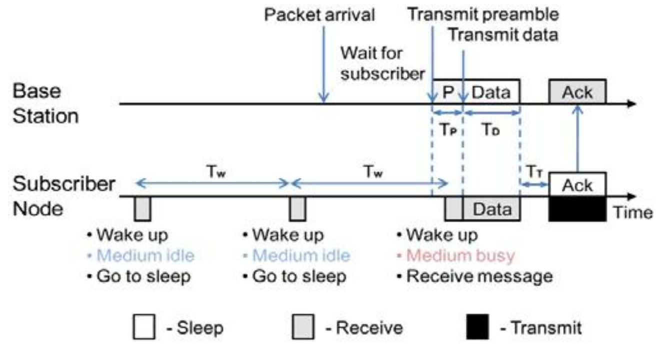


Fig 2: Preamble sampling in B-MAC

The design and implementation of B-MAC is very simple. A filter mechanism is used in B-MAC to increase reliability and channel assessment. B-MAC uses clear channel assessment (CCA) and packet backoffs for channel arbitration, link layer acknowledgments for reliability, and low power listening (LPL) for low power communication [2]. B-MAC uses CCA to decide the arrival of a packet on the wake up of nodes. No synchronization, RTS and CTS are there in B-MAC.When B-MAC is compared with another conventional S-MAC,B-MAC's flexibility results in better packet delivery rates, throughput, latency, and energy consumption than S-MAC [2].

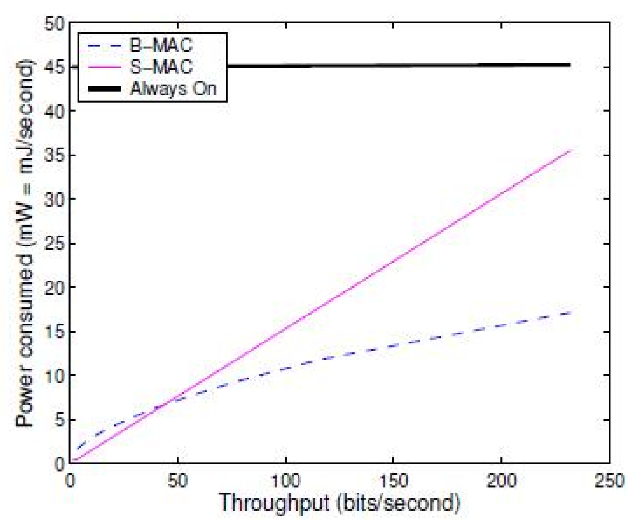


Fig 3: Comparison of B-MAC and S-MAC for power consumption in a 10-node Network [2]

## 2.3 Y-MAC : MULTI-CHANNEL MAC PROTOCOL

The single channel MAC protocols have very limited performance in a multi-channel environment. Therefore several multi-channel MAC protocols have been proposed to improve the overall network performance. Y-Media Access Control SS(Y-MAC) protocol is one of the energy efficient MAC protocol for WSNs. The goal of this protocol is to achieve both high performance and energy efficiency under diverse traffic conditions [3]. Y-MAC protocol is a TDMA-based multi-channel MAC protocol [3]. So a time slot is allocated in Y-MAC for both data transmission and data reception. The Y-MAC achieves good reception rate, low duty cycles and a steady delivery latency even under high traffic conditions, while the other single channel MAC protocols suffer due to limited reception bandwidth. Y-MAC achieves effective transmission of bursty messages under high traffic conditions, while maintaining low energy consumption [3]. The use of multiple channels can definitely increase MAC protocol performance with low energy consumption [3].

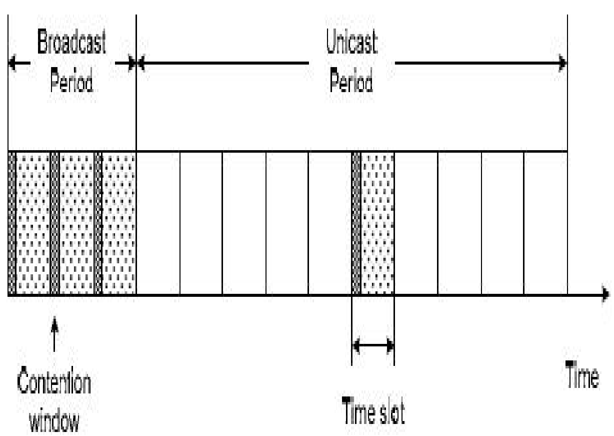


Fig 4: Frame architecture of Y-MAC [3]

In Y-MAC frame architecture, the time is divided into several fixed -length frames, and each frame is composed of a broadcast period and a unicast period [3]. The sender and receiver should have synchronization on the communication channel and transmission timing.

Y-MAC can be implemented in the RETOS operating system running on TmoteSky motes for performance analyzes. RETOS is an operating system for WSNs developed at Yonsei University which has a layered network architecture. It consists of three layers: the dynamic networking layer (DNL), the networking supporting layer (NSL), and the medium access control (MAC) layer [3]. User applications need only to interact with the DNL to deliver messages, and different routing modules can be selected taking into account the characteristics of user applications [3]. The NSL takes care of neighbourhood management and the neighbourhood information is also maintained in a table. RETOS is thus a multi-threaded operating system, so when a node receives a message it wakes up a blocked thread [3].

Extensive experiments validate the practicality of Y-MAC protocol in improved throughput and reduced message delivery latency. On comparing the multi-channel energy efficient Y-MAC protocol with an another energy efficient MAC protocol defined for dense WSNs called Crankshaft, Y-MAC outperforms Crankshaft in terms of data reception rate.

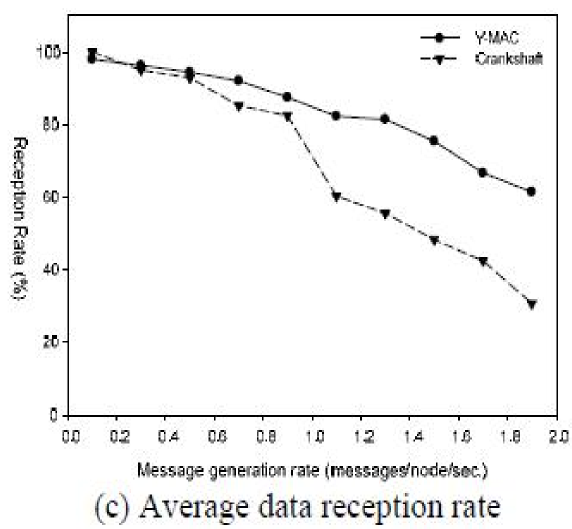


Fig 3: Comparison of Y-MAC and Crankshaft for data reception rate in multi-channel Environment [3]

## 2.4 COGNITIVE MAC (C-MAC) : A MULTI-CHANNEL MAC PROTOCOL

The emergence of Cognitive Radio (CR) has become an ultimate solution for spectrum scarcity in wireless applications. Here another multi-channel MAC protocol, Cognitive Media Access Control (C-MAC) is introduced for CR sensor networks. C-MAC operates over multiple channels, and hence is able to effectively deal with, among other things, the dynamics of resource availability due to primary users and mitigate the effects of distributed quiet periods utilized for primary user signal detection [4]. In C-MAC, each channel is logically divided into recurring superframes which, in turn, include a slotted beaconing period (BP) where nodes exchange information and negotiate channel usage [4]. A beacon is transmitted by each node in a destined beacon slot during the BP. The hidden nodes, medium reservations and mobility can be handled with this beacon.

In this scheme, a Rendezvous Channel (RC) is used as the backbone of C-MAC. The C-MAC protocol employs the concept of dynamic Rendezvous Channel (RC), which is used to coordinate nodes in different channels, for multi-channel resource reservation, quiet period (QP) coordination for incumbent detection, and so on. For making RC extremely robust to Incumbents, Backup Channel (BC) concept is also introduced here. C-MAC addresses many key challenges for the proper operation of WSNs in presence of incumbents. RC can achieve some features to manage the entire network like network wide Group Communication (GC), inter-channel synchronization, neighbourhood discovery and load balancing. C-MAC has been evaluated via both analytically and through simulations.

C-MAC has a unique channel structure where each channel has its own superframe structure. One of the available channels is identified as the RC. The other multi-channel MAC protocols use a superframe only in the common channel which requires the switching back of all network devices to the common channel on the start of every superframe.

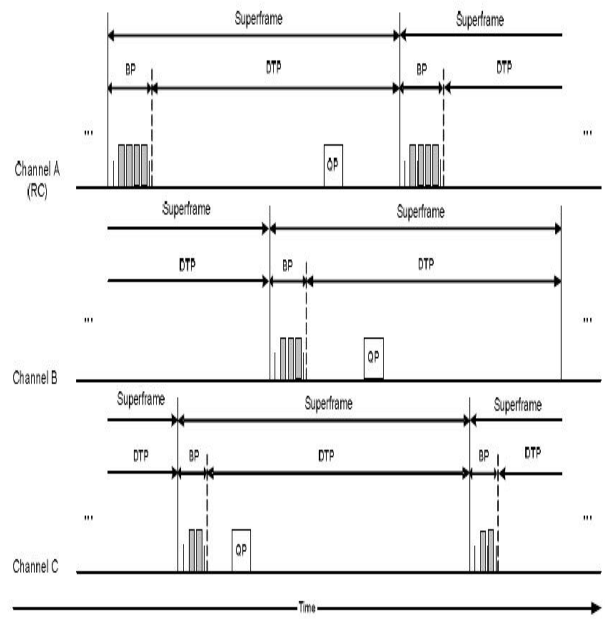


Fig 4: Multi-channel and superframe structure in C-MAC [4]

The maximum achievable throughput in C-MAC has been evaluated for number of channels and the result shows the effectiveness of C-MAC over multiple channels [4].

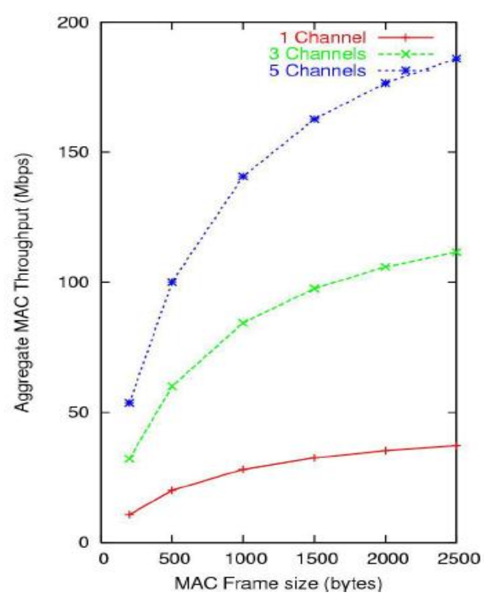


Fig 5: Maximum C-MAC aggregate throughput above the MAC layer [4]

## 2.5. MMDQS-MAC : MULTIHOP MULTI-CHANNEL DISTRIBUTED QOS SCHEDULING MAC

The Multihop Multi-Channel Distributed QoS Scheduling Media Access Control (MMDQS-MAC) scheme improves the network performance of WSNs by selecting the best channel for an individual wireless sensor node [5]. The overall network performance of WSNs is increased here by decreasing the chance of collisions and interferences. MMDQS MAC protocol utilizes parallel transmissions and also supports short packet transmissions under low traffic networks. This scheme improves the performance of aggregate throughput, probability of successful transmission, packet delivery ratio, energy consumption and average end-to-end delay [5].

When the medium is busy, all available multi-channels are utilized to reduce the channel access time of a sensor node and hence improves the WSNs performances. The multi-channel MAC schemes employed here increase the capacity of wireless access control mechanisms. These multi-channel access mechanisms maintain different transmissions in wireless links active at the same time without collision. Such multi-channel scheduling MAC assignment can eliminate the interference among different channels and therefore, no collision in the MAC layer. In this protocol, each sensor node is equipped with directional antennas and the size of MAC layer packet is very small [5].

The primary objectives of MMDQS-MAC are maximum aggregate throughput, interference-free communication and guaranteed QOS. There are three assumptions regarding the sensor nodes used in this protocol: All sensor nodes are equipped with directional antennas, All sensor nodes are stationary and Sensor nodes can choose arbitrary transmit power for data transmission [5].

The frame structure of MMDQS-MAC protocol consists a Contention Period (CP) and a Non Contention Period (NCP). The beacon frames are broadcasted during CP to perform time synchronization periodically.

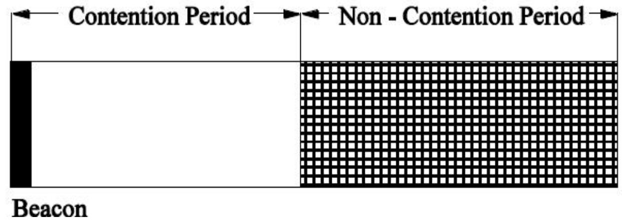


Fig 6: The frame structure of MMDQS-MAC protocol [5]

In the MMDQS-MAC protocol, the CP is of fixed length frames composed of a specified number of time slots and the period of NCP is dependent on the contention resolution of CP [5]. By minimizing idle listening and overhearing, excellent energy efficiency can be achieved here. The performance of MMDQS-MAC protocol is evaluated by comparing it with another two multi-channel MAC protocols, a Multi-Frequency Media Access Control (MMSN) and a Multi-Channel Lightweight MAC protocol (MC-LMAC). The result shows the effectiveness of MMDQS-MAC protocol over available channels.

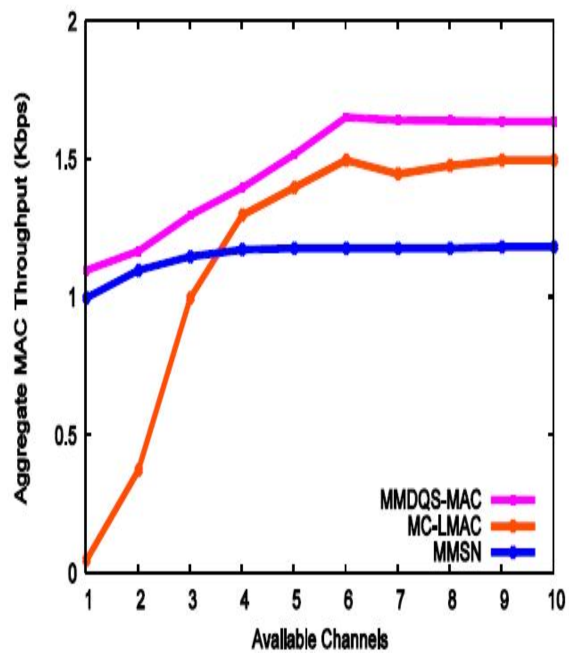


Fig 7: Aggregate throughput (Kbps) with number of available channels

## II. COGNITIVE RADIO SENSORNETWORKS (CRSNs)

Dynamic spectrum access stands as a promising and spectrum-efficient communication approach for resource-constrained multihop wireless sensor networks due to their event-driven communication nature, which generally yields bursty traffic depending on the event characteristics [9]. The Cognitive Radio (CR) technology has become a promising solution to recognize and utilize spectrum opportunities within the licensed bands while avoiding congestion and interference with the primary networks. The use of CR in WSNs has led to the emergence of a vastly unexplored field of Cognitive Radio Sensor Networks (CRSNs). CRSNs possess many potential advantages and application areas for WSNs. However the merging of CRs and WSNs can have new set of challenges also.

A cognitive radio sensor network (CRSN) can be defined as a distributed network of wireless cognitive radio sensor nodes, which sense event signals and collaboratively communicate their readings dynamically over available spectrum bands in a multihop manner to ultimately satisfy the application -specific requirements [9]. The various advantages of CRSNs include dynamic spectrum access, opportunistic channel usage, adaptability for reduced power consumption and communication under different spectrum regulations. CRSNs find its potential applications in the area of indoor sensing, multimedia, multiclass heterogeneous sensing and real time surveillance.

There are three types of CRSN architectures: Ad Hoc CRSNs, Clustered CRSNs. Heterogeneous CRSNs and Mobile CRSNs. Dynamic Spectrum management in CRSN is done by spectrum sensing, spectrum decision and spectrum handoff. These functions will prevent the overcrowding of WSNs. A cognitive radio sensor network (CRSN) opportunistically accesses the spectrum of licensed spectrum unused by other networks and supports both real-time constant-bit-rate (CBR) traffic and best effort (BE) traffic [11]. CRSN achieves a satisfactory real performance on the evaluation using various models or through simulations. When compared with other conventional WSNs, CRSNs show remarkable effectiveness in network performance.

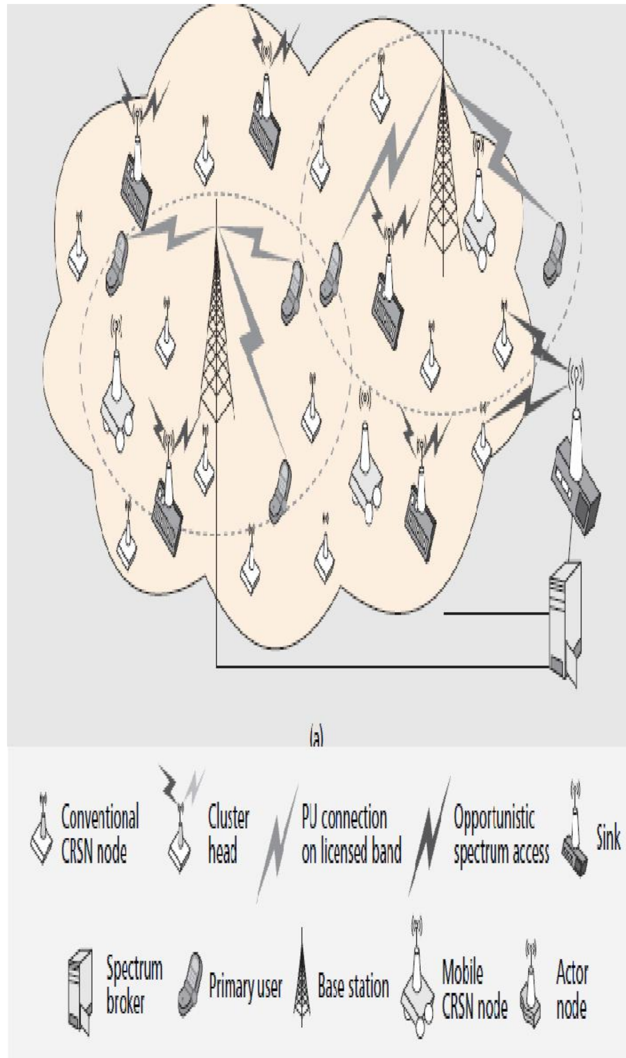


Fig 8: CRSN architecture [9]

Cognitive routing is performed in CRSNs. The CR technology could provide access not only to new spectrum, but also to spectrum with better propagation characteristics (e.g. at lower frequency bands) [10]. The advantages of CR-based WSNs can be demonstrated through analyzes and simulations in terms of range extension and protocol efficiency. Cognitive routing avoids the chances of congestion as different nodes take different routes to a common destination. By reducing the congestions and collisions in a network, the efficiency can be improved to a great extent.

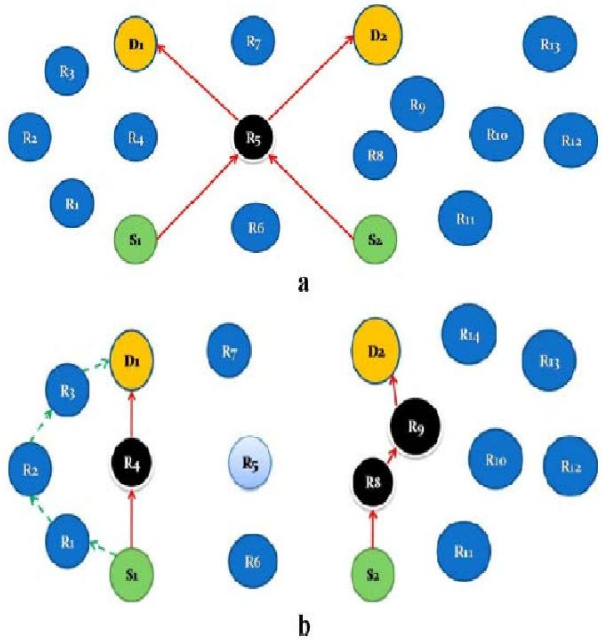


Fig 9: (a) Classical routing (b) Cognitive routing [8]

A CR-based WSN model consists of features like CR PHY Mode, Spectrum Sensing, Network Quiet Periods and Incumbent Detection Discovery. The CR channel can be compared with a 2.4 GHz channel for Communication range. For the same transmit power, the maximum range in the CR channel is almost double the maximum range in the 2.4 GHz channel, which is due to higher propagation loss in 2.4 GHz band.

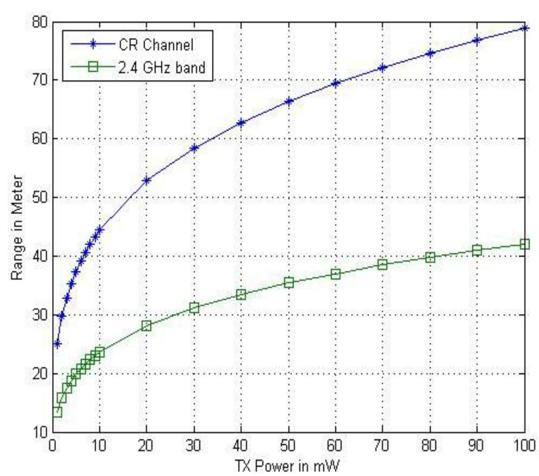


Fig 10: Communication range comparison [10]

All the network functions can be mapped onto three-layer cognitive framework.

| Layer | Sub-layer | Goals/Functions |
|---|---|---|
| Application Layer | Requirements layer | Maximize the connection time of a unicast/multicast flow in a wireless environment |
| Cognitive Layer | Cognitive specification language | Map the goal of connection lifetime to a fitness function that describes the total power utilization of the chosen route. |
| | Cognitive process | Control output power from transmitting nodes |
| | Network status sensors | Measure the following parameters:<br>• power output at each node<br>• capacity at each node<br>• network connectivity |
| Software adaptable network layer | Network API | Provide the following to cognition layer:<br>• cognition limits on possible power settings<br>• a hook for setting requested power output<br>Provide a bi-directional communication mechanism to share utilization ratios and calculate fitness function among nodes in the network. |

Table 1: Mapping of network goals/functions to the three layer cognitive framework [8]

Hence the Cognitive Radio Sensor Networks (CRSNs) maintain minimum access and end-to-end delay by accessing the available channels opportunistically for real time surveillance applications. The performance of all real time sensing applications has been further improved with the development of a new delay-constrained joint spectrum allocation and routing algorithms for CRSNs.

## IV. CONCLUSION

This paper proposes a survey of Media Access Control (MAC) protocol defined for Wireless Sensor Networks (WSNs). Both single channel and multi-channel MAC protocols exist for WSNs. The multi-channel MAC protocols outperform the single channel MAC protocols in terms of communication performance and energy consumption. The survey reveals the effectiveness of defining a MAC protocol for WSNs which improves the overall network performance. Cognitive Radio Sensor Networks (CRSNs) emerged as a promising approach for providing spectrum efficient communication all over the networks. The survey also highlights the design principles, potential advantages and application areas of CRSNs. The evaluation of CRSNs exhibits the performance improvement obtained by the use of cognitive radio in WSNs.

## REFERENCES

[1] W. Ye, J. Heidemann, and D. Estrin, "An energy -efficient MAC protocol for wireless sensor networks," in Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies., vol. 3, pp. 1567–1576, 2002.

[2] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks," in Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems, pp. 95– 107, ACM,2004.

[3] Y.Kim, H. Shin, and H. Cha, "Y-MAC: An energy-efficient multichannel MAC protocol for dense wireless sensor networks," in International Conference on Information Processing in Sensor Networks, pp. 53–63, IEEE Computer Society,2008.

[4] C. Cordeiro and K. Challapali, "C-MAC: A cognitive MAC protocol for multi-channel wireless networks," in IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, pp. 147–157,2007.

[5] Kumaraswamy M1, Shaila K2, Tejaswi V2, Venugopal K R2, S Iyengar "Multihop Multi-Channel Distributed QOS Scheduling MAC Scheme for Wireless Sensor Networks", IOSR Journal of Computer Engineering (IOSR-JCE) e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 17, Issue 2,ver 1.

[6] Bhavana Narain, Anuradha Sharma, Sanjay Kumar and Vinod Patle, "Energy Efficient MAC Protocols for Wireless Sensor Networks: A survey"International Journal of Computer Science & Engineering Survey (IJCSES) Vol.2, No.3, August 2011 DOI : 10.5121/ijcses.2011.2309 121.

[7] Ilker Demirkol, Cem Ersoy, and Fatih Alagöz, "MAC Protocols for Wireless Sensor Networks: A Survey"

[8] G.Vijay, E. Ben Ali Bdira, and M. Ibnkahla, "Cognition in wireless sensor networks: A perspective," IEEE Sensors Journal, vol. 11, no. 3, pp. 582–592, 2011.

[9] O. Akan, O. Karli, and O. Ergul, "Cognitive radio sensor networks,"IEEE Networks, vol. 23, no. 4, pp. 34–40, 2009.

[10] D. Cavalcanti, S. Das, J. Wang, and K. Challapali, "Cognitive radio based wireless sensor networks," in IEEE International Conference on Computer Communications and Networks, pp. 1–6, 2008.

[11] Zhongliang Liang and Dongmei Zhao, "Quality of Service Performance of a Cognitive Radio Sensor Network", IEEE ICC 2010 proceedings.

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