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Comparison of IEEE 802.11 and IEEE 802.15.4 for Future Green Multichannel Multi-radio Wireless Sensor Networks

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Abstract**:** Multi-channel MAC protocols have recently obtained considerable attention in wireless networking research because they promise to increase capacity of wireless networks significantly by exploiting multiple frequency bands. In this paper, we do a comparison between IEEE 802.11 and IEEE 802.15.4 and investigate the performance between both using simulations conducted in NS2. This investigation will allow us to determine the feasibility in having IEEE 802.11 being considered as a future medium for wireless sensor networks operating in a multichannel environment at high data rate with streaming data that would be a challenge for IEEE 802.15.4. More so IEEE 802.15.4 will be facing severe challenge to operate in the 2.4GHz frequency band when the IEEE 802.11n becomes popular, operating within the same frequency band.

We demonstrate through simulations that IEEE 802.11 perform better with high data rate, streaming constant bit rate and at longer range comparing to 802.15.4 which operates better with small data size at much shorter range. The outcome from this paper will be valuable for our future work in designing a multichannel MAC protocol for contention-based 802.11 WSN.

Keywords**:** WPAN, WLAN, CSMA/CA, MAC, DCF, wireless sensor networks.

1. Introduction

Wireless technologies continue to be a popular interest in the communication arena and are increasingly replacing the wired technology in a number of areas such as monitoring and control applications. They have also become an integral part of the Internet. The IEEE 802.11[1] and the IEEE 802.15.4 [2] standard play a vital role for contention based networks and divide the wireless spectrum into different spectral bands called ‘‘channels”. This allows simultaneous communications and limits interference between nodes. Also allowing the coexistence of multiple wireless networks on different channels, frequency division to increases capacity of the wireless networks in infrastructure mode by operating on different channels.

IEEE 802.11 is concerned with features such as Ethernet matching speed, long range (100m), complexity to handle seamless roaming, message forwarding, and data throughput of 2-54Mbps, while IEEE 802.15.4 on a space around a person or object that typically extends up to 10m in all directions. The IEEE 802.15 working group is formed to create WPAN standard. This group has currently defined three classes of WPANs that are differentiated by data rate, battery drain and quality of service (QoS).

The study of wireless sensor networks (WSNs) [3-8] has become a hot topic in networking due to the convergence of data and telecommunication over IP based networks that paved the way for communication technologies innovation and security provision that will see many systems such as closed-circuit TV (CCTV) rely on the premises of WSN surveillance systems for tracking and create alerts from sensors rather than standalone video circuits. The future predicts WSNs operating at high data rate for streaming data over multichannel multi-radio assignment over IEEE 802.11 networks. This paper does a comparison of IEEE 802.15.4 and IEEE 802.11 to determine such feasibility for WSN in 2.4 GHz frequency band as oppose to IEEE 802.15.4. Also the feasibility for IEEE 802.15.4 to cope in the 2.4 frequency band when the IEEE 802.11n becomes popular will be problematic, as at high traffic load 802.11n will be able to use a total bandwidth of 40MHz leaving no channel for IEEE 802.15.4 and also will not be free from channel interference of IEEE 802.11n. Since WSN involve sending all data monitored to a sink and we are concentrating on future channel assignment, we will focus this paper on the popular 2.4 GHz range of operation and the MAC sublayer to formulate our outcome for a future green multichannel multi-radio WSN. The paper is organized as follows: In Section II, we briefly details the IEEE 802.15.4 MAC protocol so as to aid the understanding of CSMA/CA and PAN coordinator. In Section III, we briefly detail the IEEE 802.11 MAC protocol so as to aid the understanding of CSMA/CA and DCF. Section IV, related work and in Sections V and VI, we formulate our focus area and discuss our simulation results. Finally, Section VII concludes the paper.

2. IEEE 802.15.4

Wireless personal area networks (WPANs) [2] are used to convey information over relatively short distances. Unlike wireless local area networks (WLANs), connections effected via WPANs involve little or no infrastructure. This feature allows small, power-efficient, inexpensive solutions to be implemented for a wide range of devices. The data rate is 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz. IEEE and ZigBee Alliance [9] have been working closely to specify the entire protocol stack. IEEE Std 802.15.4 defines the physical layer (PHY) and medium access control (MAC) sublayer specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices with no battery or very limited battery consumption requirements typically operating in the personal operating space (POS) of 10 m. It is foreseen that, depending on the application, a longer range at a lower data rate may be an acceptable tradeoff. A central controller known as the personal area network (PAN) coordinator is use to builds the network in its personal operating space. The MAC layer has two mode of operation: beacon enable and beaconless. The beacon enabled mode allows splitting of time into multiple clusters where nodes have exclusive access to the transmission channel during its active duration. In beaconless operation there is no division of time and a node competes for channel access with other nodes in its radio range using unslotted CSMA/CA algorithm. We will focus on the beaconless operation of the IEEE 802.15.4 MAC layer.

2.1 Medium access control (MAC) Sublayer

The IEEE 802.15.4 MAC sub layer controls access to the radio channel by using a Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) mechanism. This sub layer is responsible for transmitting beacon frames, synchronization and providing a reliable transmission mechanism. The MAC sublayer provides two services: the MAC data service and the MAC management service interfacing to the MAC sublayer management entity (MLME) service access point (SAP) (MLMESAP). The MAC data service enables the transmission and reception of MAC protocol data units (MPDU) across the PHY data service. Fig. 1 depicts the components and interfaces of the MAC sublayer.

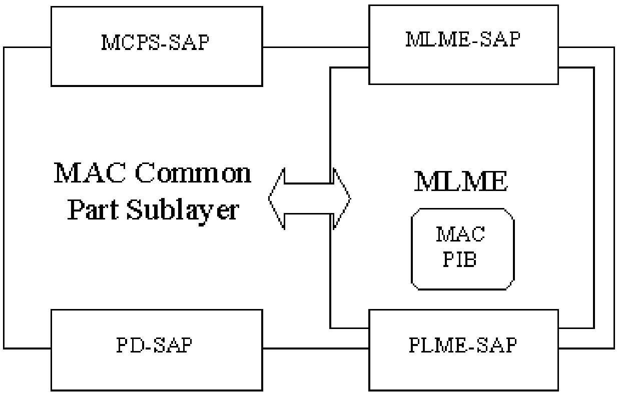

Fig. 1: The MAC sublayer components

2.1.1 CSMA-CA Algorithm

In the slotted CSMA/CA channel access mechanism each device will maintain three variables for each transmission attempt: number of backoff (NB), contention window (CW) and backoff exponent (BE). NB is the number of times the CSMA-CA algorithm is required to backoff while attempting the current transmission; this value shall be initialized to zero before each new transmission attempt. CW is the contention window length, defining the number of backoff periods that need to be cleared of channel activity before the transmission can commence. This value shall be initialized to one before each transmission attempt and reset to one each time the channel is assessed to be busy. Otherwise this value shall be initialized to two before each transmission attempt and reset to two each time the channel is assessed to be busy. The CW variable is only used for slotted CSMA-CA. In a slotted CSMA-CA system with the BLE subfield set to zero, the MAC sublayer shall ensure that, after the random backoff, the remaining CSMA-CA operations can be undertaken and the entire transaction can be transmitted before the end of the contention access period (CAP). If the number of backoff periods is greater than the remaining number of backoff periods in the CAP, the MAC sublayer will pause the backoff countdown at the end of the CAP and resume it at the start of the CAP in the next superframe. If the number of backoff periods is less than or equal to the remaining number of backoff periods in the CAP, the MAC sublayer will apply its backoff delay and then evaluate whether it can proceed. If the MAC sublayer can proceed, it will request that the PHY perform the CCA in the current superframe. If the MAC sublayer cannot proceed, it will wait until the start of the CAP in the next superframe and apply a further random backoff delay before evaluating whether it can proceed again.

In a slotted CSMA-CA system with the BLE subfield set to one, the MAC sublayer shall ensure that, after the random backoff, the remaining CSMA-CA operations can be undertaken and the entire transaction can be transmitted before the end of the CAP. The backoff countdown shall only occur during the first macBattLifeExtPeriods full backoff periods after the end of the interframe space (IFS) period following the beacon. If the MAC sublayer can proceed, it shall request that the PHY perform the CCA in the current superframe. If the MAC sublayer cannot proceed, it shall wait until the start of the CAP in the next superframe and apply a further random backoff delay [step (2)] before evaluating whether it can proceed again.

If superframe structure is used in the PAN, then slotted CSMA-CA shall be used. If beacons are not being used in the PAN or a beacon cannot be located in a beacon-enabled network, unslotted CSMA-CA algorithm is used. In both cases, the algorithm is implemented using units of time called backoff periods, which is equal to aUnitBackoffPeriod symbols. In slotted CSMA-CA channel access mechanism, the backoff period boundaries of every device in the PAN are aligned with the superframe slot boundaries of the PAN coordinator. In slotted

CSMA-CA, each time a device wishes to transmit data frames during the CAP, it shall locate the boundary of the next backoff period. The mechanism to be followed before accessing the channel is depicted in fig. 2 of the CSMA-CA flow chart.

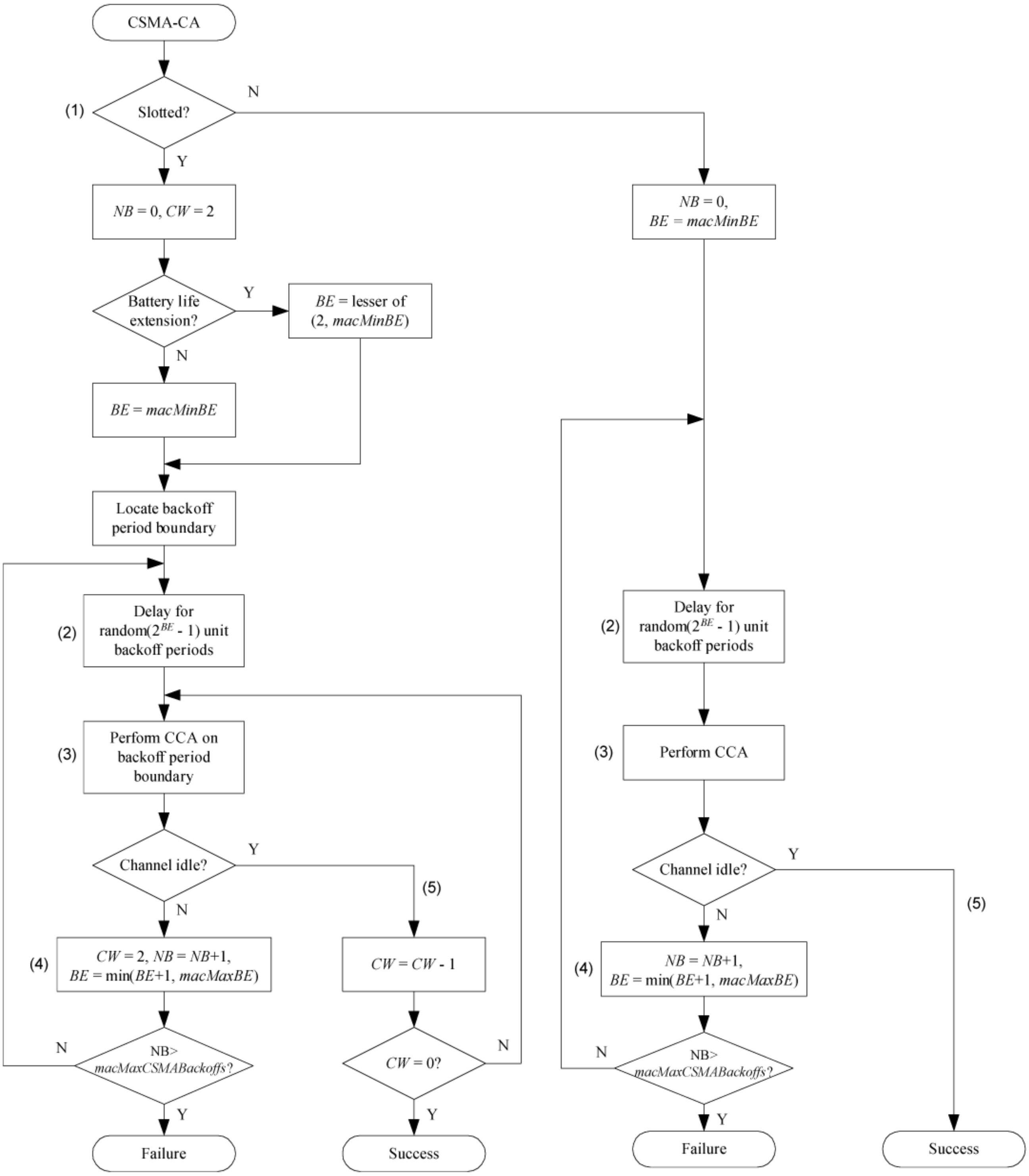

Fig. 2: CSMA-CA flowchart

2.1.2 Channels

There are 16 channels between 2.4 and 2.4835GHz as shown in Fig. 3. The standard also allows dynamic channel selection, a scan function that steps through a list of supported channels in search of beacon, receiver energy detection, link quality indication, channel switching. The physical layer provides the capability to perform the clear channel access (CCA) according to at least one of the following three methods:

- CCA Mode 1: CCA shall report a busy medium upon detecting any energy threshold.
- CCA Mode 2: Carrier sense only. CCA shall report a busy medium only upon the detection of a signal compliant with this standard with the same modulation and spreading characteristics of the physical layer that is currently in use by the device. This signal may be above or below the energy detection (ED) threshold.
- CCA Mode 3: Carrier sense with energy above threshold. CCA will report a busy medium using a logical combination of:

- Detection of a signal with the modulation and spreading characteristics of this standard and
- Energy above the ED threshold, where the logical operator may be AND or OR.

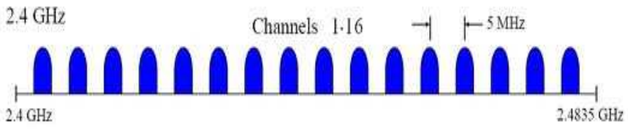

Fig. 3: Channels for IEEE 802.15.4

3. IEEE 802.11

3.1 MAC Sublayer

The MAC sublayer [1] of the IEEE 802.11, defines the distributed coordination function (DCF), the point coordination function (PCF), the hybrid coordination function (HCF). The focus will be on the DCF that allows automatic medium sharing.

3.1.1 Basic access

The basic access mechanism called DCF is a carrier senses multiple access collision avoidance (CSMA/CA) mechanism. The CSMA protocol allows a station wishing to transmit to sense the medium, if the medium is busy it differ its transmission but if the medium is free then the station is allowed to transmit. CSMA is very effective when the medium does not have high traffic, since all medium transmit with minimum delay. Station transmitting at the same time results in collision as the protocol initially is design for single channel transmission. CA allows the medium that is busy and defers to wait and allow the medium to free for a specific time called distributed interframe space (DIFS) then the station is allowed to transmit. Fig. 4 illustrates the basic access with immediate access when the medium is free.

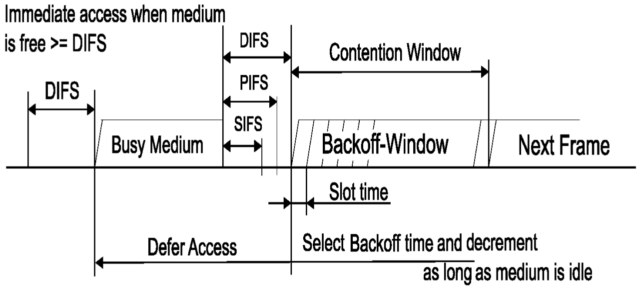

Fig. 4: Basic access method

3.1.2 DCF

DCF [1] is the basic and mandatory MAC mechanism of legacy IEEE 802.11 WLANs that allows for automatic medium sharing between compatible physical layers through the use of CSMA/CA and a random backoff time following a busy medium condition. In addition, all individually addressed traffic uses immediate positive acknowledgment (ACK frame) where retransmission is scheduled by the sender if no ACK is received.

The CSMA/CA protocol is designed to reduce the collision probability between multiple stations accessing the medium, at the point where collisions would most likely occur. Multiple collision occur more frequently after a busy period when there are multiple stations waiting on the medium to transmit their data. This situation necessitates a random backoff procedure to resolve medium contention conflicts through carrier sense (CS) functions. CS can be performed both through physical and virtual mechanisms. The virtual CS mechanism is achieved by distributing reservation information announcing the impending use of the medium. It reduces the probability of two stations colliding that cannot hear each other.

3.1.3 CS mechanism

Both the physical and virtual CS functions are used to determine whether the medium is busy or idle. When either function indicates a busy medium, the medium will be considered busy otherwise, it shall be considered idle. The virtual CS mechanism is provided by the MAC referred to as the network allocation vector (NAV) which predicts the future traffic on the medium. The CS mechanism combines the NAV state and the station's transmitter status with physical CS to determine the busy/idle state of the medium. The NAV also act as a counter, which counts down to zero at a uniform rate. When the counter is zero, the virtual CS indicates that the medium is idle and when nonzero indicates busy.

3.1.4 Random backoff time

In this procedure, a station with a packet to transmit waits until the medium becomes idled, when it senses the medium is busy. When the medium is left idled for the duration of Distributed Interframe Space (DIFS) period, the station sets its Backoff timer to *random()***aSlotTime*. *aSlotTime* is set at a time which is equal to the time needed at any station to detect the transmission of packet from any other station. *Random()* = Pseudo-random integer drawn from a uniform distribution over the interval [0,CW], where CW is an integer within the range of values of the physical layer characteristics of the minimum and maximum window (aCWmin and aCWmax),

aCWmin $\leq$ CW $\leq$ aCWmax. In 802.11 the default value of *aSlotTime* is 20 µs for 802.11b and 9 µs for 802.11a/g, if no medium activity is indicated for the duration of a particular backoff slot then the Backoff slot is decreased by *aSlotTime*. If the medium is sensed as busy during a backoff slot, the backoff timer is suspended until the medium is idled for the duration of DIFS period, then the backoff timer will resume again. When the backoff timer reaches zero, transmission will start and after the transmission gives an acknowledgement indicating whether or not the transmission was successful. If the transmission was successful, the station will set its backoff timer again before transmitting the next packet. However, the control window (CW) will take the next value in the series every time there is an unsuccessful attempt to transmit. This allows either station retry counter to increment, until the CW reaches the value of the maximum window size (aCWmax). Once it reaches aCWmax, the CW shall remain at the value of aCWmax until the CW is reset; fig. 5 illustrates the exponential increase of CW. The CW will reset to aCWmin after every successful attempt in transmitting data or after a station long retry count.

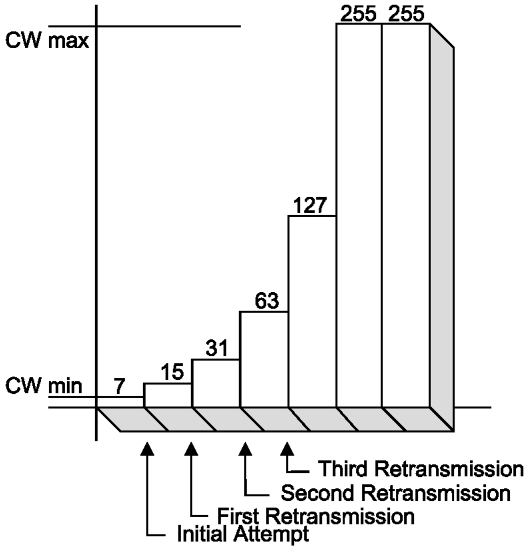

Fig. 5: Exponential increase of CW

The backoff procedure will be invoked when a station is ready to transfer a frame and finding the medium busy as by the indication of the physical or virtual CS mechanism. The backoff procedure will also be invoked when a transmitting station infers a failed transmission. The station will set its backoff timer to a random backoff following a DIFS period during which the medium is determined to be idled. The station performing the backoff procedure will use the CS mechanism to determine any activities during the backoff slot. If there is no activity indicated the backoff procedure will decrement it backoff time by aSlotTime. Fig. 5 illustrate a backoff procedure with multiple stations deferring and go into random backoff.

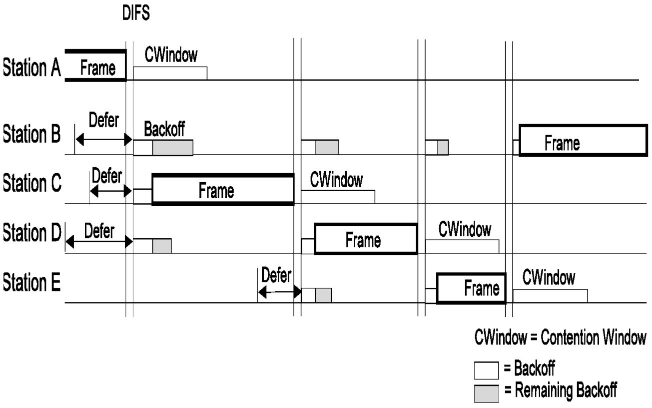

Fig. 6: DCF backoff procedure

3.1.5 Channels

In IEEE 802.11, there are 14 possible channels in the 2.4 GHz frequency range. The channel width is 22 MHz and each channel is spaced 5 MHz apart. This creates overlap between channels, and IT professional will often use channels 1, 6, and 11 non-overlapping to avoid using the overlapping channels. Fig. 7 illustrates the channel centre frequency which is defined in sequential 1.0 MHz steps beginning with the first channel. Occupied channel bandwidth will meet all applicable local geographic regulations for 1 MHz channel spacing. The rate at which the PMD entity will hop is governed by the MAC. The hop rate is an attribute with a maximum dwell time subject to local geographic regulations.

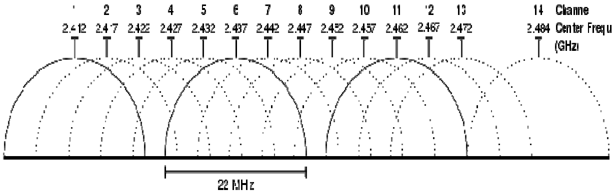

Fig. 7: Channel centre frequency for IEEE 802.11 in the 2.4 GHz range

4. Related Work

A number of researchers [10-21] have used a combination of both the IEEE 802.15.4 and the IEEE 802.11 networks within the WSN for comparison and evaluation in different scenarios or 802.11 is use as access point (AP) and at cluster heads to relay 802.15.4 sensor network data to sink and other network servers and applications. In [10] they introduce distributed algorithms to optimize the 802.15.4 performance under varying 802.11 interference pattern. Nakatsuka et al [12] adjust the 802.11 b/g protocol to prevent inter-channel interference between 802.15.4 in order to have both protocols operating in the same frequency channel, they conclude that interchannel interference between 802.14.5 and 802.11 b/g can be mitigated by sharing time controlling traffic of 802.11 b/g but they have not considered the effect of 802.11n when it becomes popular with the multiple input, multiple output (MIMO) effect and significant increase in the maximum raw data rate from 54 Mbps to 600 Mbps with the use of four spatial streams at a channel width of 40 MHz. Bertocco et al [15] presented in their work a new simulator allowing cross-layer analysis of interference arising among 802.15.4 and 802.11 and predicts possible interference effect, this is still a work in progress for the researchers.

5. Formulation

Both IEEE 802.15.4 and IEEE 802.11 use the CSMA/AC mechanism for contention based network. The slotted CSMA/CA mechanism adopted with the PAN mode of IEEE 802.15.4 is different from the well-known IEEE 802.11 CSMA/CA scheme. The main differences involve the time slotted behaviour, the backoff algorithm, and the clear channel assessment (CCA) procedure used to sense whether the channel is idle. The differences are outline as follows:

- In IEEE 802.15.4, each operation (channel access, backoff count, CCA) can only begin at the boundary of time slots, which recall is termed backoff periods. In IEEE 802.11, the notion of a slot exists only insofar as backoff counting is concerned.
- In IEEE 802.15.4, only when the backoff counter reaches zero does the node sense the channel (CCA). In IEEE
- 802.11, nodes are constantly sensing while in backoff, thereby incurring an additional consumption of energy.
- In IEEE 802.15.4, the backoff counter of a node decreases regardless of whether the channel is idle

or busy. In contrast, in IEEE 802.11 the backoff counting pauses whenever the channel becomes busy.

- In IEEE 802.15.4, unlike in IEEE 802.11, the contention window size is reset to its minimum value at the beginning of each retransmission attempt.

When IEEE 802.15.4 and IEEE 802.11 use the same channels, their CSMA/CA functions enable them to share the same time slot. When the same channels are used by both it cause 802.15.4 to suffer long delays while having 802.11 with a higher frequency range provides priority access of the channel in most cases. An overlap between them can adversely impact on the operation of IEEE 802.15.4, since it is a low power protocol which uses a small channel width compared to the transmitted power levels and channel width used by IEEE 802.11. The frequency bands in which these interference issues are more critical for wireless network include the 2.4 GHz Industrial, Scientifical and Medical (ISM) band. See Fig. 8 showing 802.11 and 802.15.4 channels in the 2.4 GHz ISM band.

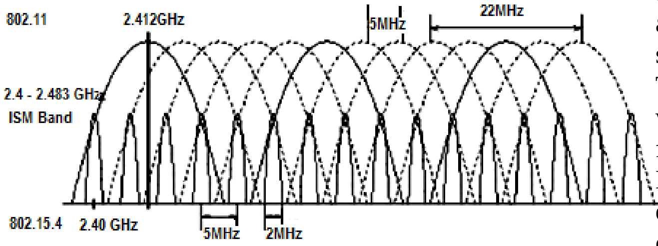

Fig. 8: Channels compare of 802.11 and 802.15.4

In non-beacon enabled mode and under moderate data rate, the new IEEE 802.15.4 standard, compared with IEEE 802.11, is more efficient in terms of overhead and resource consumption. It also enjoys a low hop delay on average. However, 802.11n can have a data rate as high as 248 Mbps in the same frequency band as the other standards. The major large in increase in data rate and range is achieved by using technique called Multiple-Input Multiple-Output (MIMO). MIMO uses more than one sender and receiver antennas and combines this with special coding techniques in order to squeeze even more data through the same frequencies. For example in Polepalli et al [20] their test bed results showed that overlap with IEEE 802.11n control channel causes severe deterioration in both loss rate and packet latency for IEEE 802.15.4 traffic and that the overlap is much more serious with the extension channel of 802.11n. IEEE 802.11 is better suited for high rate sensor and voice applications, while 802.15.4 is better suited for low rate sensors and devices used for control applications that do not require high data rate but must have long battery life, low user interventions and mobile topology. The new short range, low power, low rate wireless networking protocol, 802.15.4, complements the high data rate technologies such as WLAN and open the door for many new applications when using a combination of both because the predicted environment of these devices demands maximization of battery life, the protocols tend to favour the methods which lead to it, implementing periodic checks for pending messages, the frequency of which depends on application needs. However when the environment intends to focus purely on high data rate with streaming data such as multimedia systems and sensor surveillance system that rely on their image and data over wireless networks, the consideration of 802.11 need to be the focus as such systems will not be able to cope with periodic transmission. We will be investigating the effect of both 802.11 and 802.15.4 by conducting simulations using NS2, to analyse the effect with different data rate and at different ranges.

6. Simulation Results and Discussions

We use simulation model based on NS2 [22] using the existing MACs protocol stack and the work done for cognitive radio cognitive network (CRCN) [23] GUI, SNR lab/Michigan Technological University and the Hyacinth model [24] for multi-channel, single-radio. This model already provided many radio models including 802.11 and 802.15.4, this NS2 also incorporates different topology and traffic generator which enable the creation of different simulation scenarios. Different simulation scenarios will be studied according to three different performance metrics: aggregate throughput, delivery ratio and access delay. The sensor nodes are randomly placed in a 1000x1000m^2 area. The number of nodes is 50 and simulation run for 300s. Data will be sending to a sink node. The distributed coordination function of IEEE 802.11 and IEEE 802.15.4 is used as the MAC layer. We do not assume large networks that are densely deployed; we consider a sensor network with continuous streaming data that could be deployed for organization, parks and vehicular traffic not for remote monitoring. In this instance nodes will always be static and powered and as such the depletion of battery life is not considered. We will be simulating CBR traffic to be sent every 2 second to prevent buffer overflow and to replicate streaming data.

In figs. 9-11 we simulate streaming data within a 10m range of each node at data rate of 100kbps for both 802.11 and 802.15.4. We have observed in fig. 9 that after 20 nodes both protocols start experiencing high delay in transmitting data packet. There were not much difference in behavioural pattern among each protocol; this shows that even though 802.11 was design for high data rate, the simulation shows that it can be performed at lower data rate and short range; however, CSMA/CA protocol overhead such as the contention process, interframe spacing, physical layer level headers (Preamble + PLCP) and acknowledgment frames impact heavily on small data size making 802.11not feasible to operate at low data rate. The high delay experience by 802.15.4 at low data rate result from streaming data rate which may have create buffer overflow and constant backing off as all nodes are contending for the medium and the succession of the data is not periodic. These prevent a better performance for 802.15.4. The packet delivery ratio and aggregate throughput in figs. 10 and 11 respectively experience a similar behavioural pattern where there is little variation between both protocols. 802.11 perform slightly better after 30 nodes than 802.15.4; again this shows that 802.15.4 cannot perform well with streaming data even if operating at low data rate and would not be feasible for sensor network with multimedia or surveillance system that rely on image and data over the wireless medium.

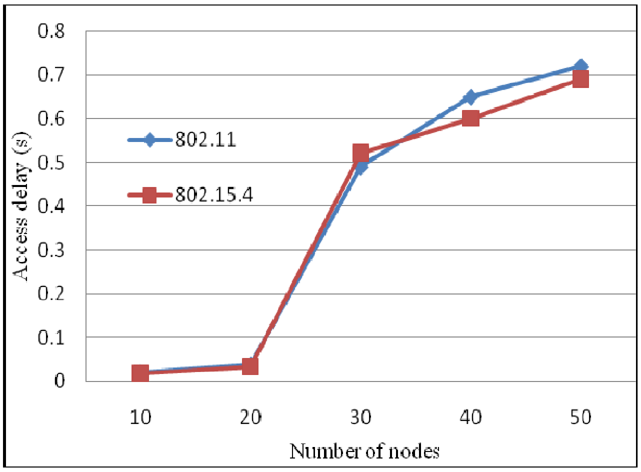

Fig. 9: Delay comparison for 802.11 and 802.15.4 at 10m range and data of 100kbps

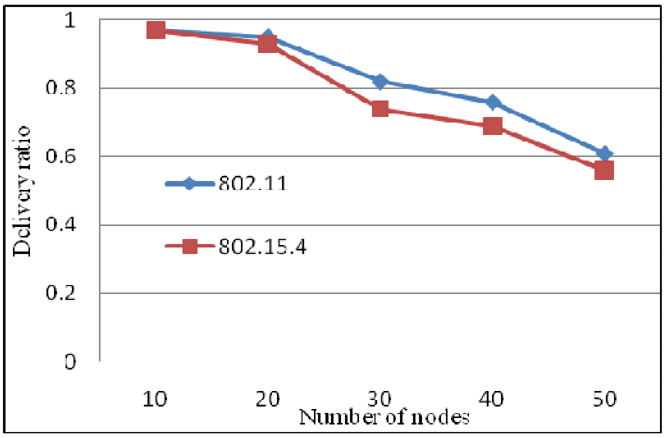

Fig. 10: Delivery ratio comparison for 802.11 and 802.15.4 at 10m range and data of 100kbps

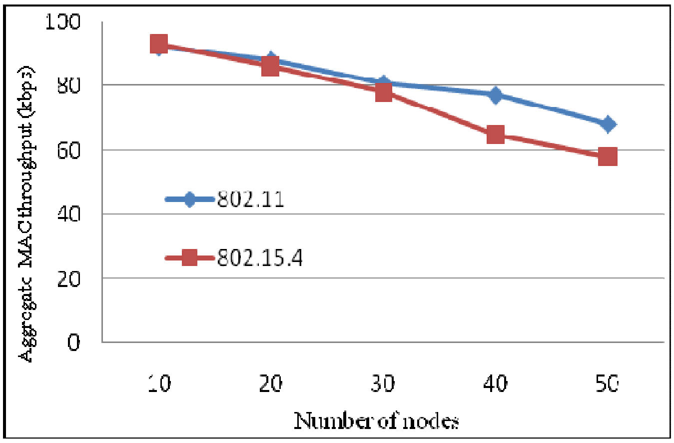

Fig. 11: Throughput comparison for 802.11 and 802.15.4 at 10m range and data of 100kbps

In figs. 12-14 we simulate streaming data within a 50m range of each node at data rate of 2Mbps for both 802.11 and 802.15.4. We have observed in fig. 12 that 802.11 experience low delay in packet transmission but gradually start to increase access delay after 30 nodes. This is normal as all nodes are contending for the same medium. The result shows that 802.11 out perform 802.15.4 by over 65%. The poor performance of 802.15.4 occurred because of the high data rate, streaming data and the distance to transmit data these effect have cause buffer overflow, data loss, constant backing off of the medium and which does not allow the capability to cope under such severe constraint. 802.15.4 performs well at short range and with small packet size; therefore it is not likely for 802.15.4 to operate under such pressure more so with streaming data. The packet delivery ratio and aggregate throughput in figs. 13 and 14 respectively experience a similar behavioural pattern where 802.11out perform 802.15.4. Severe degradation experience when operating at 50m with streaming data rate at 2Mbps; again this shows that 802.15.4 cannot perform well at long range with high data rate streaming and therefore not feasible for sensor multimedia or surveillance system with streaming data.

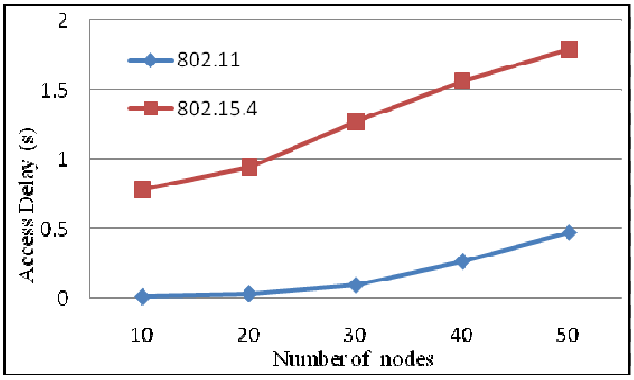

Fig. 12: Delay comparison for 802.11 and 802.15.4 at 50m range and data of 2Mbps

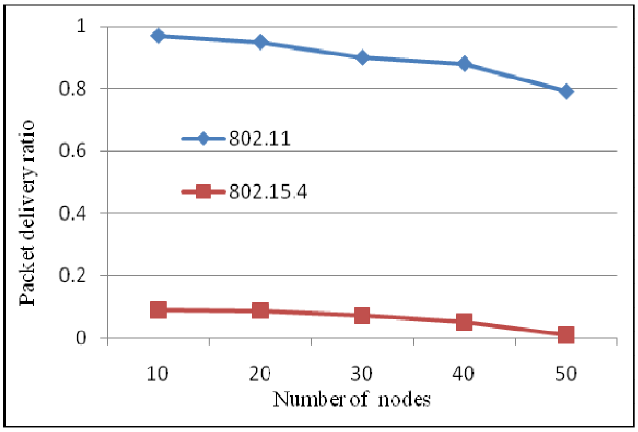

Figure 13: Delivery ratio comparison for 802.11 and 802.15.4 at 50m range and data of 2Mbps

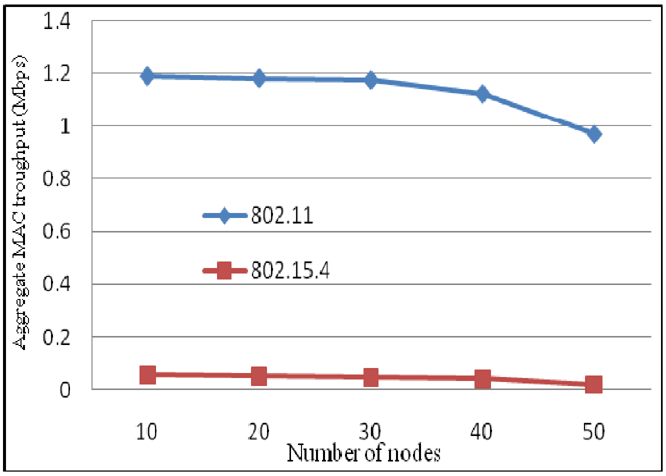

Fig. 14: Throughput comparison for 802.11 and 802.15.4 at 50m range and data of 2Mbps

7. Conclusion and Future Work

In this paper we have briefly details the IEEE 802.15.4 MAC protocol so as to aid the understanding of 802.11 and 802.15.4 CSMA/CA scheme. We have investigated and evaluated the performance of both protocol through simulation results conducted in NS2 to make a rational decision which protocol is feasible for future WSN operating with multimedia or surveillance system in a multichannel multi-radio environment. The result obtained from simulation outcome from streaming data with 100kbps and 2Mbps at 10 and 50m range respectively, shows that 802.15.4 cannot perform well at long range with high data rate streaming and or at low data rate with streaming data. The aggregate throughput, delivery ratio and access delay performance metric was used, where 802.15.4 performed very poorly at high data rate and having 802.11 perform slightly better after 20 nodes at low streaming data rate. We therefore conclude that 802.15.4 is not feasible for sensor multimedia or surveillance system with streaming data for future multichannel multi-radio systems.

Having investigating the performance between IEEE 802.11 and IEEE 802.15.4 it is feasible to focus the future WSN using 802.11 contention-based protocols. We will be proposing a multichannel distributed coordinate function over single radio for WSNs. The design proposal will be tested with simulation scenarios from NS2. We will further enhance the proposal by introducing multi-radio at the sink node. The overall goal for such design proposal is to utilize multichannel transmission for future 802.11 wireless sensor surveillance systems to process video data for automated real-time alerts and also to consider a more cost effective solution when IEEE 802.15.4 is unable to operate in the already crowded 2.4GHz when IEEE 802.11n becomes popular.

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