Abstract—Recently 60 GHz communication has emerged as a potential candidate for high speed, short range radio communication. However, since the range of 60 GHz is too small, it is used only at the last meter. Optical links are used to feed these last hop access points. Thus, a radio over fiber (RoF) based wireless personal area network (WPAN) with 60 GHz radio is proposed. This hybrid network is known Fi-Wi. Specifically, RoF based WPAN architecture employing IEEE 802.15.3c MAC for 60 GHz frequency band is proposed in this paper. Based on detailed performance analysis of MAC, suitability of IEEE 802.15.3c in RoF indoor networks is examined carefully. Limitations of using IEEE 802.15.3c, due to the additional delay introduced by fiber distribution network are highlighted. An analytical method to solve the sectored carrier sense multiple access with collision avoidance (CSMA/CA) using directional antenna is proposed. Analysis of different acknowledgment (ACK) mechanisms in different physical channel conditions are performed, which is helpful in selecting appropriate ACK policy based on the requirements of applications. We provide a complete and thorough analysis of Fi-Wi WPAN architecture based on IEEE 802.15.3c. This is expected to help designers and practitioners.

I. INTRODUCTION

High speed wireless multimedia applications such as uncompressed video streaming, IPTV and online gaming are becoming more and more popular these days. Thus, the demand for high speed, high quality, reliable and affordable communication technology is increasing. RoF is being considered as a promising technology to deliver the data rate of the order of Gbps to the end users. On the other hand, about 5 GHz of spectrum around 60 GHz frequency has been unlicensed for use worldwide. The combination of RoF and 60 GHz radio in the last meter promises to be the potential alternative to the indoor networking. With very high datarate connectivity through fiber to homes, it is but natural to extend this to each room in the indoor environment. Furthermore, with 60 GHz last meter wireless connectivity, users will have mobility support and ease of use. Thus, this hybrid Fiber-Wireless (Fi-Wi) technology is now getting much attention. Higher capacity of Optical Fiber together with high speed wireless links at 60 GHz can provide the much sought after Multi Gbps transmission required for IPTV, online gaming and uncompressed video streaming applications with flexibility of wireless access. Uncompressed data stream, in particular, is useful for mobile platforms, which have severe constraints with respect to computation.

Several standardization groups such as IEEE 802.11ad, ECMA and IEEE 802.15.3c have been formed in order to accelerate the standardization efforts for high speed communication at 60 GHz frequency band (57 GHz to 66 GHz with varying bands in different countries). IEEE 802.15 working group for WPAN has come up with IEEE 802.15.3c PHY and MAC specification for data rate of up to 5 Gbps [1]. The wave propagation in 60 GHz is fundamentally different from that of lower frequency bands such as 2.5 GHz. The most important feature of 60 GHz wireless propagation is its high path loss. Further, the transmission in the 60 GHz band is highly directional, which is beneficial to overcome the high path loss. It provides highly spatial multiplexing capability as well [2], [3], [4]. Another important characteristic is its limited ability to diffract around the obstacles which makes it suitable mainly for line of sight (LOS) communication with an approximate range of around 10 m [5]. This forces network designers to place access points at short intervals, such as at least one access point in every room. This can be difficult to manage in in-home network and also expensive to cover large buildings or offices. To make network management easy, centrally managed network architecture with simple access points (cost effective) is highly desirable. RoF technology can facilitate the high data rate capability of optical fiber and inherent flexibility of wireless systems for cost effective indoor applications.

In RoF systems all the functioning related to radio access control, signal generation, distribution and processing is done in a centralized home communication controller (HCC). HCC has all the network management capabilities while radio access point (RAP) works as a relay point just to forward the packets sent by HCC. Because of the small range, every room should have at-least one RAP providing wireless connectivity to all the devices in the room and is connected to the HCC through a high bandwidth fiber optic cable.

Most of the work on RoF has been aimed at wireless service delivery for long distances which mainly focuses on the physical layer technology and component architectures [6], [7], [8], [9]. There are few works which have studied the popular MAC protocols in the WPANs. In [10], an architecture for RoF based indoor network is proposed. In [11], IEEE 802.11 and ETSI HiperLAN/2 are employed in RoF indoor
networks. In [12], performance of IEEE 802.16, WiMax in RoF networks is analyzed. It is shown that centralized MAC protocols are better suited for RoF indoor networks. In [13], MAC constraints on using IEEE 802.11 in RoF are highlighted and it is concluded that if minimal changes in MAC parameters are adopted, IEEE 802.11x can become a suitable candidate for RoF based WLAN systems.

Das et al. [14] have investigated the performance of RoF network employing IEEE 802.11a/g MAC. An experimental setup was created and the feasibility of employing 802.11a/g in RoF network was demonstrated. Further, Mjeku et al. [15] have investigated the effects of request to send (RTS) and clear to send (CTS) mechanisms of IEEE 802.11 in RoF indoor network and an RTS-CTS threshold selection mechanism based on packet size is proposed. In [16], IEEE 802.15.3c based proof of concept RoF indoor network architecture is demonstrated which satisfies the IEEE 802.15.3c PHY requirements (i.e., error vector magnitude and data rates). [16] investigates only the PHY performance of IEEE 802.15.3c based RoF indoor network architecture and MAC performance analysis is not carried out, which is important due to the delay introduced by fiber distribution network. Given its centralized MAC architecture and high speed PHY support, IEEE 802.15.3c can be a potential MAC for RoF systems.

In this paper, we focus on MAC layer performance analysis of IEEE 802.15.3 based RoF indoor network. The work done in this paper would provide important guidelines for setting up IEEE 802.15.3c based RoF indoor network. With our results one can select an optimal ACK policy for 802.15.3c based Fi-Wi networks. Impact of per sector beamwidth on contention access period (CAP) throughput is provided which would be helpful in determining the appropriate number of sectors around RAP. This would help in maximizing the superframe (SF) throughput and in turn the throughput of the entire network. Our main contributions in this paper are: (i) suitability examination of IEEE 802.15.3c in RoF indoor networks; (ii) detailed throughput performance analysis of IEEE 802.15.3c MAC protocol (both sectored CSMA/CA protocol and time division multiplex based allocation) in RoF indoor network; and (iii) investigation of effects of physical channel error rate and packet size on throughput for different ACK policies.

The rest of the paper is organized as follows. In Section II, we provide a brief introduction to IEEE 802.15.3c and RoF network architecture employing IEEE 802.15.3c. Later, in Section III we provide an analysis of CAP duration in the SF which is followed by Section IV providing analysis of channel time allocation period (CTAP) for different ACK mechanisms in different physical channel conditions. We conclude in Section V.

II. RoF INDOOR NETWORK ARCHITECTURE

IEEE 802.15.3c is a standard defined for ad hoc communication system for devices (DEVs) to communicate with each other in a piconet with a radius of around 10 m. One device assumes the role of a piconet coordinator (PNC) of the piconet. The piconet either operates in omni mode or in quasi-omni mode in which directional communication is supported. Timing in IEEE 802.15.3c is based on the Super Frame (SF) boundaries set by the PNC as shown in Fig. 1. The SF consists of three parts: beacon, CAP and CTAP. Beacon is used to communicate the management information for the piconet. CAP is used to communicate commands and asynchronous data if it is present in the SF. Channel access mechanism used in CAP period is CSMA/CA. CTAP is used for isochronous data transmission. Channel time allocation (CTA) in CTAP uses TDMA, which is allotted during CAP period. It is guaranteed that no other DEVs will compete for the channel during the indicated time duration of the CTA allotted to a DEV.

RoF network architecture employing IEEE 802.15.3c MAC is shown in Fig. 2. HCC is the central management unit for in-home networks. HCC is responsible for signal processing (RoF signal generation, baseband processing etc.), joint optical and wireless resource allocation and network management. With HCC many network related tasks could be centralized. Every room has at least one RAP, which forwards the packets to its destinations, be it devices in rooms or PNC within HCC. RoF architectures for large coverage areas such as outdoor LANs, require long fiber lengths resulting in higher MAC delays which can degrade the network throughput. However, RoF technology is suitable for indoor Gigabit WLAN due to small required fiber lengths (100-300m is sufficient for even large buildings) thus overcoming the stringent delay requirements for MAC functions. Therefore, we adopt IEEE 802.15.3c MAC protocol for indoor RoF based architecture. In our architecture, IEEE 802.15.3c PNC is also part of HCC and thus responsible for coordination amongst the devices in individual rooms and scheduling traffic. As 60GHz can not penetrate through the walls, RAPs in different rooms can operate at common frequencies. In order to avoid collisions...
in fiber domain, RAPs in different rooms are allocated separate wavelengths for communication with HCC to facilitate simultaneous transmission.

Since coverage of a RAP is limited to a single room, frequent handovers are expected when a user moves in the indoor environment. If each RAP is PNC capable, each time a device moves from one room to another, it has to start re-association process. Moreover a break in very high data rate session can be unpleasant to the users. Whereas, if all the RAPs are connected to a single PNC, then a device moving from one room to another remains the member of the same piconet (belonging to the same PNC). Thus PNC within HCC can easily facilitate the session transfer from one RAP to another with lesser delay. Thus a centralized coordinator can simplify the network management functionalities.

III. STUDY OF CONTENTION ACCESS PERIOD (CAP)

Carrier sense multiple access with collision avoidance (CSMA/CA) employing binary backoff procedure is the medium access mechanism used during CAP. The PNC controls the commands and type of data that may be sent during the CAP. The unique feature of 802.15.3c CSMA/CA is that contention is allowed in a round robin fashion in different sectors of PNC. As shown in Fig. 3, only those devices which fall in a particular sector of RAP can contend for channel during the allotted time communicated during beacon period of SF. We name this as Sectored CSMA employing directional antennas (SD-CSMA/CA). Beamwidth of directional antennas is assumed to be equal to the angular width of a sector. Since PNC allocates different CAP slots for different sectors, problem of deafness that is very prominent in directional antennas, is eliminated. Further, since devices in a sector are very close to each other, it also reduces the problem of hidden terminals.

A. Throughput analysis

For simplicity of analysis, we consider a single room scenario. RAP in the room is connected to the HCC via optical fiber. Devices are assumed to be uniformly distributed in the circular area surrounding 60 GHz RAP as shown in Fig. 3. The reason to place access point at the centre of the circle is to maximize the coverage. If total number of sectors around RAP are $Q$ and $\theta$ is the angular width of each sector, then relation between $Q$ and $\theta$ is given by $Q = \frac{n\theta}{2\pi}$. Let $n$ represent number of total devices, on an average each sector will have $n_k = \frac{n\theta}{2\pi}$ devices contending for channel at a given time. If $n\theta/2\pi$ is not an integer value then number of devices in first $r$ sectors ($1 \leq k \leq r$) are taken as $n_k = \lfloor (n\theta/2\pi) \rfloor$ and $\lceil (n\theta/2\pi) \rceil - 1$ for rest of the $Q - r$ sectors ($r + 1 \leq k \leq Q$), where $r = \text{rem}(n, Q)$. $\text{rem}(\cdot)$ represents remainder of the division $n/Q$. Let $\tau_k$ be the transmission probability of each device in the $k^{th}$ sector. Let $p_k$ be the probability of collision experienced by a packet in that sector given that it is transmitted on the channel. $p_k$ is also known as the conditional collision probability and is assumed to be a constant and independent of the number of retransmission attempts. For better readability, we omit the subscript $k$ from $\tau$ and $p$ here onwards, however for each sector, transmission probability $\tau$ and collision probability $p$ will depend on the number of devices in that sector and might be different. A transmitting station suffers a collision when any of the $n_k - 1$ devices transmit at the same time. Hence, relation between $\tau$ and $p$ in a sector is given by,

$$p = 1 - (1 - \tau)^{n_k - 1}. \quad (1)$$

CSMA/CA employs random back-off selection mechanism in which backoff window size increases by a factor of two with every retransmission attempts until the maximum retransmission limit is reached. Whenever channel is sensed idle devices decrease their backoff timer by a slot time. A slot time is represented by $\sigma$. Let $W_0$ be the basic window size, then window size at $i^{th}$ retransmission stage is $W_i = 2^i W_0$. In case of IEEE 802.15.3c, maximum value of $i$ is 3 and $W_0 = 8$. To analyze the CSMA/CA, Markov chain based analytical model is widely used [17]. Fig. 4 shows the Markov chain representation of different backoff states. The backoff counter, which decreases at the start of every idle time slot, can be modelled as a stochastic process $B(t)$. When $B(t)$ reaches zero, the station transmits the packet and generates a new $B(t)$ based on whether the packet is successfully transmitted or not. We define $s(t)$ to represent the backoff stage. Since it is assumed that $\tau$ is constant over all the time slots for all the devices and $p$ is constant and independent of the number of previously suffered collisions by the packet, a two dimensional Markov process $(s(t), B(t))$ can be defined.
The method to solve the markov chain based model in [17] is based on the analysis of steady state probabilities of backoff states. However, CSMA/CA procedure in the IEEE 802.15.3c differs from the CSMA/CA procedure of IEEE 802.11. At the end of CAP period in a superframe, backoff counters of devices are reset and fresh backoff states are generated in the CAP part of the next superframe [18]. This unique characteristic of contention access in IEEE 802.15.3c MAC makes steady state analysis inapplicable. In order to obtain the relation between \( \tau \) and \( p \), we derive an expression which is based on the average time spent by a frame before it leaves the MAC queue and average number of transmission attempts made by the device in that duration. If \( E[TS] \) is the average time spent by a packet before it leaves the MAC queue and \( E[TA] \) is the average number of transmission attempts during \( E[TS] \), then, transmission probability \( \tau \) can be given by,

\[
\tau = \frac{E[TA]}{E[TS]}
\]  

(2)

Since the channel state is observed at discrete time instants with interval equal to slot time \( s \), average idle time (number of idle time slots) spent by a packet in the MAC queue before it is successfully transmitted or dropped is equal to the total idle slots spent by the packet. If \( m \) is the maximum packet retransmission limit, then \( E[TS] \) expressed as the summation over all the possible backoff stages is given by,

\[
E[TS] = \sum_{i=0}^{m} (P_{suc}(i)E[B_i]),
\]  

(3)

where \( E[B_i] \) is the average backoff slots accumulated by a device in backoff stage \( i \) and \( P_{suc}(i) \) is the probability that a device transmits successfully in stage \( i \), that is given by \( P_{suc}(i) = p^i \times (1-p), i < m \). Assuming that backoff selection mechanism is uniformly distributed over the backoff window \([0,W] \), \( E[B_i] \) can be expressed as,

\[
E[B_i] = \frac{1}{2} \sum_{k=0}^{2^i} 2^k W_0, \quad 0 \leq i \leq m.
\]  

(4)

Because of finite number of retransmission attempts, probability that a packet reaches \( m^{th} \) (maximum allowed) backoff stage is \( p^m \). It really does not matter whether a packet is successfully transmitted or dropped after maximum number of retransmissions has been reached since packet is removed from the system. Therefore, from (3) and (4),

\[
E[TS] = \sum_{i=0}^{m-1} \left( p^i \times (1-p) \frac{1}{2} \sum_{k=0}^{i} (2^k W_0) \right) + p^m \frac{1}{2} \sum_{k=0}^{m} (2^k W_0).
\]  

(5)

\( E[TA] \), the average number of transmission attempts during the period of \( E[TS] \) can be calculated as,

\[
E[TA] = 1(1-p) + 2(1-p)p + \cdots + (m)(1-p)p^{m-1} + (m+1)p^m
\]

\[
= \frac{1 - p^{m+1}}{1-p}
\]  

(6)

On substituting the value of \( E[TS] \) from (5) and \( E[TA] \) from (6) into 2, we can solve (1) and (2) to obtain the values of \( \tau \) and \( p \).

As per CSMA/CA, a random time slot can either be idle or busy. Further, a busy slot can either result in a successful transmission or a collision. A slot remains idle if no station out of \( n_k \) stations transmits; thus \( P_i \) is given by,

\[
P_i = (1-\tau)^{n_k}.
\]  

(7)

Probability of a busy slot with successful transmission (only one device transmits and the rest \( n-1 \) devices are idle) is given by,

\[
P_s = n_k \tau (1-\tau)^{n_k-1},
\]  

(8)

and probability of collision during a busy slot (more than one devices are transmitting simultaneously) is given by,

\[
P_c = 1 - n_k \tau (1-\tau)^{n_k-1} - (1-\tau)^{n_k}.
\]  

(9)

\( S_{CAP} \), the normalized throughput of a sector is defined as the fraction of time that the channel is used to transmit payload successfully. Let \( T_i \) be the duration of an idle time slot, \( T_b \) is the duration of a successful transmission and \( T_c \) is the duration of a failed transmission, then normalized throughput for \( k^{th} \) sector can be computed as,

\[
S_{CAP_k} = \frac{E[Payload\ Information\ in\ a\ slot\ time]}{E[Length\ of\ a\ slot\ time]}
\]

\[
= \frac{P_i E[Payload]}{P_i T_i + P_s T_s + P_c T_c}.
\]  

(10)

Where \( E[Payload] \) is the average size of payload packet and \( T_i = SIFS + T_{CCADetectTime} \). In IEEE 802.15.3c, CAP duration is used for asynchronous transmission of commands such as association request, association response, channel time request (CTRQ) and channel time response (CTRQ). In our analysis, we take CTRQ and CTRP commands as the references for calculation of timing. Thus, \( T_c = T_{CTRQ} + 2SIFS + T_{CTRQ} + t_{prop} + BIFS \) and \( T_c = T_{CTRQ} + T_{out} + t_{prop} + BIFS \). Where, \( T_{CTRQ} \) is the duration of CTRQ command, \( T_{CTRQ} \) is the duration of CTRQ command, \( t_{prop} \) is propagation (roundtrip) time, \( BIFS \) is the backoff inter-frame space, \( SIFS \) is the short inter-frame space and \( T_{out} \) is the ACK or response timeout. Further, \( S_{CAP} = \frac{1}{Q} \sum_{k=1}^{Q} S_{CAP_k} \) gives the average of normalized throughput considering all the Q sectors.

B. Consideration of fiber length

If a station senses that the channel is busy then after BIFS period it again senses the channel. After BIFS, it resumes decrementing the back-off counter if the channel is found to be idle. In an IEEE 802.15.3c piconet, BIFS period ranges from
4.2 to 6.5 μs, $t_{\text{prop}}$ is 30 ns for a distance of 10 m in wireless medium which is negligible. But in the presence of fiber, the extra propagation delay has to be taken into consideration. Let us take the case when there is no packet in the air and still the station which has just finished transmission is waiting for an ACK packet. Within this time duration, medium appears idle for other devices and these devices would wait for BIFS period and start transmission (if backoff counter of any of the device becomes zero) and thus will collide with the pending response or ACK packet. In order to allow CSMA/CA to work properly, the maximum fiber length should be such that round trip delay does not exceed the BIFS period. Taking into account the speed of light in fiber as 194.81 m/μs (for a refractive index of 1.62), for a BIFS period of 4.2 μs, maximum allowable fiber length is 427 m. This ensures that round trip transmission delay is always less than the BIFS duration. For analysis, a safe choice of 300 m long fiber (which introduces a round-trip delay of 3 μs) is taken which seems to be sufficient to cover an average sized home area. However, to compensate the fiber delay, ACK timeout has to be increased by 3 μs of delay introduced by the fiber network.

C. Numerical results and discussion

In our simulations, we assume that devices are uniformly distributed around RAP. Values of parameters used are taken from the IEEE 802.15.3c and summarized in Table I. Signal conversion times from electrical to optical and optical to electrical domains are assumed to be negligible. Fig. 5(a) shows the CAP throughput without fiber (normal IEEE 802.15.3c piconet) and with RoF architecture (fiber length of 300 m) for a sector beamwidth of $\theta = 360^\circ$ (omni). In the presence of fiber, CAP throughput drops only by 1 – 2% (see Fig. 5(a)). Such a minimal drop in throughput is insignificant. Therefore, a slight change in the ACK timeout due to delay introduced by 300 m of fiber length does not affect the CSMA/CA performance. Further, in Fig. 5(b) we compare the CSMA/CA throughput performance for different beamwidth sectors in presence of fiber. It shows the throughput for angular coverage of $45^\circ$, $90^\circ$, $180^\circ$ and $360^\circ$ which corresponds to total number of sectors as 8, 4, 2 and omni-directional, respectively. As seen in the figure, with increase in the number of devices, throughput performance is better for narrow beamwidth sectors as compared to that of wider beamwidth sectors. This is due to the fact that in a narrow beamwidth sector less number of devices will contend for the channel. Thus, probability of collision is reduced and per sector throughput is improved. Switching time for the antennas to switch from one sector to another is taken into consideration (0.5 μs). Despite some amount of time being consumed in switching from one sector to another, throughput is improved because time to switch from one sector to another is much less compared to time wasted in a single collision. Therefore, when more number of devices are present, it is better to narrow down the sector’s angular width to reduce number of collisions. On the contrary, if there are less number of devices, less number of sectors can serve the purpose easily which is evident from the above results. Hence, based on the total number of devices associated with a RAP, appropriate number of antenna sectors can be determined.

IV. ANALYSIS OF CHANNEL TIME ALLOCATION PERIOD

The time allocation mechanism for CTAP part of a SF is based on time division multiplexing. CTAP is mainly used for isochronous data streams. Channel time is allocated during the CAP period. To ensure reliable transmissions, CTAP uses three ACK mechanisms. Other than Immediate ACK $\text{Imm-Ack}$, IEEE 802.15.3c uses two more ACK mechanisms, delayed ACK and block ACK denoted as $\text{DiLy-Ack}$ and $\text{Blk-Ack}$ respectively. Absence of any of these ACK frames is
denoted as No−Ack scheme. Detailed description of these mechanisms can be found in [1].

A. Throughput calculation for different ACK schemes

We assume fixed physical channel bit error rates (BERs) $p_{hdr}$ and $p_{data}$ for header and data parts of a frame respectively. ACK frames, if requested, are sent at the requesting data frame header rate. If $L_{hdr}$, $L_{ack}$ and $L_{data}$ are the lengths of base header, ACK and data, respectively. Then probability of successful transmission of a frame is given by [19],

$$P_{suc} = (1 - p_{hdr})^{(L_{hdr}+L_{ack})}(1 - p_{data})^{L_{data}}. \quad (11)$$

Let $T_{suc}$ is the time taken by a successful transmission attempt and $T_{fail}$ is the time taken by a failed transmission attempt. The average time taken by a frame after $n_r$ retransmission attempts is given by,

$$T_{avg} = \sum_{i=0}^{n_r} |P_{suc}(1 - P_{suc})^i(iT_{fail} + T_{suc}) + (1 - P_{suc})^{n_r+1}(n_r + 1)T_{fail}|. \quad (12)$$

For Imm-Ack mechanism, $T_{suc}$ and $T_{fail}$ are given by,

$$T_{suc} = T_{pre} + T_{hdr} + T_{data} + T_{ack} + 2SIFS + t_{prop} \quad (13)$$

$$T_{fail} = T_{pre} + T_{hdr} + T_{data} + RIFS + t_{prop}. \quad (14)$$

For Dly-Ack and Blk-Ack with burst size $K$ are given by the following equations respectively,

$$P_{suc} = (1 - p_{hdr})^{(K\times L_{hdr}+L_{Dly-Ack})} \times (1 - p_{data})^{KL_{data}}. \quad (15)$$

$$T_{suc} = K(T_{pre} + T_{hdr} + T_{data}) + T_{Dly-Ack} + (K-1)MIFS + 2SIFS + t_{prop}. \quad (16)$$

$$T_{fail} = K(T_{pre} + T_{hdr} + T_{data}) + RIFS + t_{prop}. \quad (17)$$

Let $\rho$ is the CTAP fraction of an SF, then average packet throughput during CTAP ($S_{CTAP}$) is,

$$S_{CTAP} = \rho \frac{L_{data}(1 - (1 - P_{suc})^{n_r+1})}{T_{avg}}. \quad (18)$$

B. Numerical results and discussion

Fig. 6 shows the CTAP throughput for different frame sizes with BER = $10^{-3}$. Fig. 7 shows the CTAP throughput vs BER.
data part of a frame and for header part RS(49, 33) is applied. We have taken the block size, ‘I’, equal to 8.

For BER of $10^{-3}$, Blk-Ack gives the best performance amongst all the ACK mechanisms. Imm-Ack obtains the least throughput because, for each frame in Imm-Ack mechanism an ACK frame is mandatory. No-Ack performance is always better than Dly-Ack however, due to absence of retransmission, it is not possible to recover the lost frames. When channel conditions are extremely good, No-Ack can be used due to its simplicity. When packet size increases all the throughput curves come closer to the Blk-Ack. Fig. 7 shows the throughput performance for varying BERs for a fixed packet size of 50 KB. For the packet size of 50 KB, when BER value is between $10^{-4}$ and $10^{-2}$, Blk-Ack out performs all the other ACK schemes irrespective of the channel conditions. But, as soon as BER reaches $10^{-2}$, throughput performance for all the ACK mechanisms deteriorates very rapidly. We found that only for the packet size below 10 KB (not shown in figure) Imm-Ack emerges better than the Blk-Ack and Dly-Ack when BER is more than $10^{-2}$. However, for packet size greater than 10 KB, Blk-Ack always outperforms other ACK schemes irrespective of the channel conditions. This is a very important result. Therefore, for packet size greater than 10 KB, it is only the requirement of application such as delay bounds which needed to be taken care of because group ACKs perform better irrespective of the channel conditions. While using frame aggregation there are two main factors which can cause delays: (i) the frame arrival rate; (ii) the complexity of frame aggregation procedure and (iii) block size. All three of these can affect the delay requirement of application. For example, high definition video streaming has very stringent delay requirements. Therefore, for given BER, packet size and fiber length, appropriate ACK mechanism should be selected that matches the delay constraints of the application.

V. CONCLUSION

In this paper, we provided performance analysis of IEEE 802.15.3c MAC protocol for RoF based indoor networks. The analysis covered key parameters related to hybrid CSMA/CA MAC protocol. A novel analysis method for CSMA/CA incorporating the unique feature of isolated sector based contention access, where devices reset their backoff counters after every superframe was given. It has been shown that if a slight change in the ACK timeout is adopted, IEEE 802.15.3c can be a suitable candidate for the indoor Fi-Wi network. It is shown that based on total number of devices, appropriate number of sectors for CAP period could be easily decided. We have also discussed the effects of different ACK mechanisms on CTAP throughput. It is found that group ACKs perform better than the Imm-Ack in most of the cases. We can conclude that an adaptive ACK selection mechanism based on cross layer information (i.e., frame size, application delay requirement, traffic arrival rate and channel BER performance) is better. We have presented an accurate analysis of IEEE 802.15.3c in RoF which in itself would help further accurate analysis and will guide building architecture for indoor RoF networks.

Next, we plan to determine and fix the functionalities of RAP in order to ensure proper MAC operations to support directional communications together with cost effective and easily deployable network architecture.

REFERENCES