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Research Article

A Cross-Layer Approach in Sensing and Resource Allocation for Multimedia Transmission over Cognitive UWB Networks

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We propose an MAC centric cross-layer approach to address the problem of multimedia transmission over cognitive Ultra Wideband (C-UWB) networks. Several fundamental design issues, which are related to application (APP), medium access control (MAC), and physical (PHY) layer, are discussed. Although substantial research has been carried out in the PHY layer perspective of cognitive radio system, this paper attempts to extend the existing research paradigm to MAC and APP layers, which can be considered as premature at this time. This paper proposed a cross-layer design that is aware of (a) UWB wireless channel conditions, (b) time slot allocations at the MAC layer, and (c) MPEG-4 video at the APP layer. Two cooperative sensing mechanisms, namely, AND and OR, are analyzed in terms of probability of detection (P_d), probability of false alarm (P_f), and the required sensing period. Then, the impact of sensing scheduling to the MPEG-4 video transmission over wireless cognitive UWB networks is observed. In addition, we also proposed the packet reception rate- (PRR-) based resource allocation scheme that is aware of the channel condition, target PRR, and queue status.

1. Introduction

Limited available spectrum and inefficient utilization of spectrum necessitate the use of Cognitive Radio (CR) approach to exploit the existing wireless spectrum opportunistically. Cognitive radio concept was first coined by J. Mitola [1] and can be defined as a radio that is capable of sensing its environment, learning about its radio resources and user/application requirements, and adapting behavior by optimizing its own performance in response to user requests [2]. In CR networks, primary users (PUs) shall be protected while secondary or cognitive users (CUs) access the spectrum either in an overlay or an underlay mode. It is the responsibility of a CU to ensure that its existence is not felt by the PU. In overlay mode, CU uses higher transmission power. However, it is only applicable if the CU can ensure that the targeted spectrum is completely free of signals of other systems. While in underlay mode, CU is allowed to co-exist in the same spectral and temporal domains with the PU by lowering the amount of transmit power to avoid unintended interference.

Federal Communication Commission (FCC) in its report in 2002 [4] authorized the unlicensed use of Ultra wideband (UWB) in 3.1–10.6 GHz and defined a spectral mask that specifies the power level radiated by UWB systems within this band to be near the thermal noise floor (i.e., −41.3 dBm/MHz). Thus, UWB device can easily coexist with PU using underlay mode. However, sensing is still vital to cognitive UWB (C-UWB) user in order to detect and avoid unnecessary interference to any PU. Most of existing research in cognitive radio had been mainly dedicated to the physical aspect of the cognitive radio design. Recently, only few research efforts were carried out to investigate the impact of sensing mechanism to the upper layer performance such as in [5–8]. To the best of our knowledge, none of the existing works exploit a cross-layer strategy between APP,

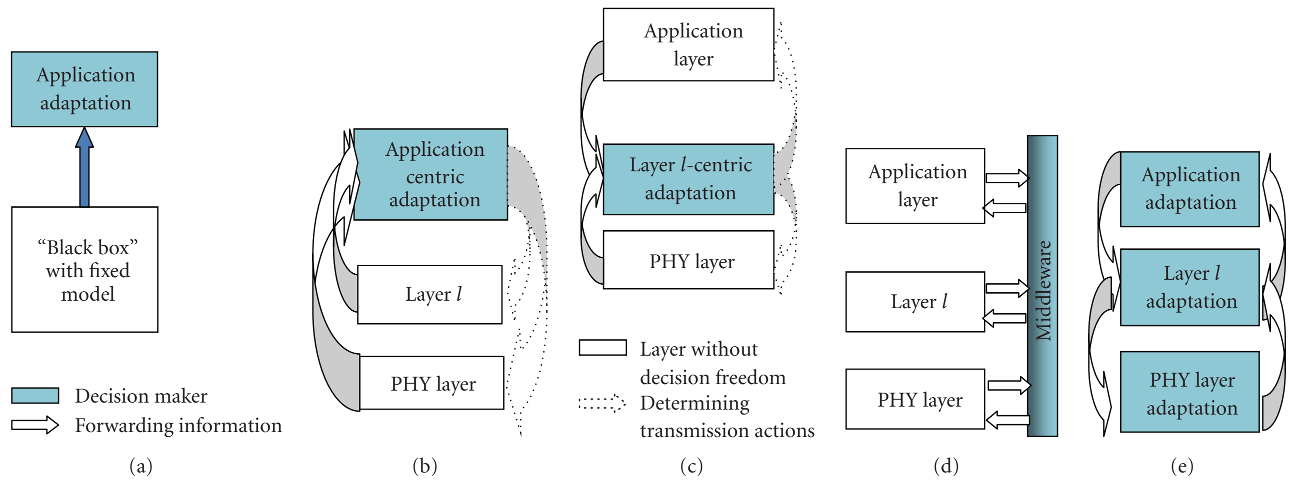

Figure 1: Conceptual illustration of cross layer optimization [3].

MAC, and PHY layers. Therefore, this paper proposes a novel MAC centric cross-layer design that is aware of the dynamic time-varying UWB wireless channel at the PHY layer and the target Quality of Service (QoS) for multimedia delivery, thus providing optimal sensing scheduling and adaptive resource allocation.

Consequently, a C-UWB node needs to consider several requirements simultaneously such as, user and application preferences, its own capabilities such as, battery status and channel conditions before any adaptation actions are taken. A compromise point, which can be regarded as optimization, is to be attained between these requirements. Hence, we believe that cross-layer design is the best suited approach for C-UWB.

Cross-layer design provides opportunities for significant performance improvements by selectively exploiting the interactions between layers, and therefore, has attracted a lot of attentions in recent years. Cross-layer optimization methods can be categorized into application adaptation, application-centric adaptation, middle layer centric approach, middleware-based adaptation, and autonomous adaptation [3] as shown in Figure 1.

Additionally, [9] introduced cognitive engine (CE) architecture that removes the distance between layers on the edges and allows parallel communications among layered protocol stacks, sensors, and memories. Each design approach has its pros and cons. Hence, the best cross-layer design solution is subject to the application requirements, used protocols, algorithms at each layer, and complexity.

Considering MPEG-4 video transmission at the APP layer, the impact of losing I-frame on the received video quality is more significant than P or B frames due to video frame dependencies. Thus, MAC should schedule the video packet optimally based on its priority, dependency, and delay deadlines. Furthermore, MAC shall also take advantage of the dynamic nature of wireless channel conditions at the PHY layer to adapt its action accordingly. For instance, more time slots are allocated to users with good channel conditions to improve the throughput. While at the APP layer, smaller quantization level (means coarser video) is assigned to user that experience bad channel conditions in order to reduce the bit error rates.

In view of that, we consider the MAC centric cross layer design which is aware of MPEG-4 QoS requirements and PHY channel conditions. AND and OR-rule cooperative sensing techniques are analyzed and the required sensing period for MAC layer scheduling is determined. Packet reception rate- (PRR-) based resource allocation is proposed to calculate the optimal time slot allocation for each user. Then, the impact of cross-layer design on MPEG-4 video transmission is evaluated.

The rest of this paper is organized as follows. Section 2 describes several related works on cross-layer design across APP, MAC, and PHY layer. Our proposed system design and approach is presented in Section 3. Results and analysis are given in Section 4. Finally, conclusion and future recommendations are drawn in Section 5.

2. Related Works

The allocation of system resources is constrained vertically across layers and horizontally among users for a system with cross-layer design. The bandwidth consumption for use in the application layer should not exceed the achievable capacity by the physical layer vertically, while allocating these resources to one user would horizontally affect the performances of the other users due to the limited amount of resources or interference of simultaneous usage. In addition, a dynamic temporal resource allocation should be adopted due to time-varying channel conditions and traffic source characteristics.

In the Time Division Multiple Access- (TDMA-) based MAC protocol, the main issue is the sharing of the time slots among the wireless users. Basically, scheduling algorithm is deployed in such networks and the wireless users will need to dynamically compete for transmission with each other. A game theoretic pricing mechanism resource allocation was considered in [10] where each user sends messages that represent their network-aware resource demands and corresponding prices to the Central Spectrum Moderator (CSM). Then the CSM will determine the suitable policy to divide the available resources among all users, while in [11], base station sets a price on the resource, and each mobile user determines its average resource request depending on the announced price and its own source utility characteristics.

Explicitly for C-UWB system, sensing activity is crucial to determine spectrum holes before any adaptation or management action can be taken. Sensing information can be a consideration for QoS requirements especially in multimedia application as it can assist C-UWB to dynamically allocate appropriate resources in accordance to the time-varying channel condition [12]. In most cases, CR device has to postpone all its transmission during spectrum sensing. Thus, sensing activity should be scheduled accordingly and sensing period should be allocated appropriately to avoid any negative impact on video application that is more sensitive to delay. For instance, if a longer time is allocated for sensing, the overall throughput will decrease. Conversely, the probability of accurately detecting spectrum holes will be reduced if the sensing time is not sufficiently allocated.

In [6], digital fountain codes are used to distribute multimedia contents over unused spectrum and also to compensate the packet losses due to PU interference. Sensing activity is scheduled at the start of every group of picture (GOP). However, how the sensing activity is scheduled at the MAC protocol is not discussed in detail. Hong and Liang [5] proposed adaptive spectrum sensing that is aware of channel state information (CSI) and queue state information (QSI). Both CSI and QSI spectrum sensing is used to decide when to perform sensing and data transmission. However, the sensing time is fixed to 20%–50% of the super frame size. We argue that this allocated sensing period is too long and inappropriate for multimedia transmission.

To take into consideration the characteristics of multimedia traffic in the cross-layer design, Rhee et al. [13] carried out simulation studies on time slot allocation based on maximum I-P-B frame size. Then, the packets are transmitted based on FIFO scheduling. However, the maximum I-P-B frame size is fixed during the whole transmission without considering the varying channel conditions. In [14], the authors proposed a cross layer solution to jointly optimize the packet scheduling by explicitly considering varying channel condition and multimedia data characteristic. Though, the method of obtaining channel conditions is not clearly elaborated. Furthermore, sensing time is not taken into account in their cross-layer design.

From the literature, we observe that there is a significant research gap for a cross layer design between APP, MAC, and PHY layers especially for multimedia transmission over C-UWB network. Motivated from the above findings, the paper is devoted to linking the spectrum sensing at the physical layer with the optimal resource allocation to meet the QoS requirements set by the multimedia application. The cross-layer framework is similar to our previous work in [15, 16] which is aware of APP, MAC, and PHY layers parameters. The framework serves as a guideline to our overall research work in realizing a complete solution of the C-UWB system. However, the main contribution of this paper will be on the PRR-based resource allocation and the impact of sensing activity on multimedia transmission.

3. Proposed Cross Layer Design

3.1. System Model. The considered cross layer framework followed our previous works in [15, 16]. Assuming TDMA-based MAC protocol, each user will be assigned an optimal time slots for data transmission and channel sensing in accordance with their channel conditions and queue status. The current dynamics at each layer is described by the state as shown in Figure 2. APP layer forwards its current state information which consists of video frame priority, delay deadlines, and dependency pattern to the MAC layer. At the same time, MAC also receives the current channel conditions, represented by Signal-to-Noise ratio (SNR), and also the appropriate sensing time from PHY layer. Based on the received information and its own queue status, MAC will determine the optimal time slot allocation, quantization level, and schedule the packet accordingly. The decisions are then forwarded to the respective layers for actions. At the APP layer, adaptive source coding is performed by changing the quantization (Q) level. The Q-level can be adjusted at every start of the GOP structure. On the other hand, MAC layer schedules the sensing and data transmission in accordance with the PRR based time slot allocation, while the PHY layer performs adaptive modulation and coding to allow data transmission rate adaptation.

At the PHY layer, the channel quality experienced by the C-UWB user is represented by

$$\mathrm{SINR} = \frac{P_{ti}h_{ij}}{\eta B + \sum_{k=1}^{M} a_k P_{ti} h_{kj}}, \tag{1}$$

where P_{ti} is average transmit power of node i, h_{ij} is signal power attenuation, h_{kj} is signal power attenuation of the other nodes k, η is background noise energy, B is bandwidth, M is number of nodes, and a_k is orthogonality factor. In equation (1), the first term of the denominator represents the Additive White Gaussian Noise (AWGN), and the second term represents multiuser interference (MUI). In UWB system, the bandwidth B is so large that the AWGN noise is significantly larger than MUI. Hence, the term MUI can be assumed negligible. Therefore, Signal-to-Inteference Noise ratio (*SINR*) can be rewritten as

$$\mathrm{SINR} \approx \mathrm{SNR} = \frac{P_{ti}h_{ij}}{\eta B}. \tag{2}$$

Ghassemzadeh and Tarokh in [18] proposed a propagation model based on 300,000 frequency response measurements that were carried out in a UWB network. Based on the field measurement, he presented the UWB path loss model as below

$$L_{ij} = \left[L_0 + 10\alpha \log_{10}\left(\frac{d_{ij}}{d_0}\right)\right] + S; \quad d_{ij} > d_0, \tag{3}$$

where L_0 is path loss at reference distance, α is path loss exponent, and S is shadowing. In this study, L_0 of 50.5 dB,

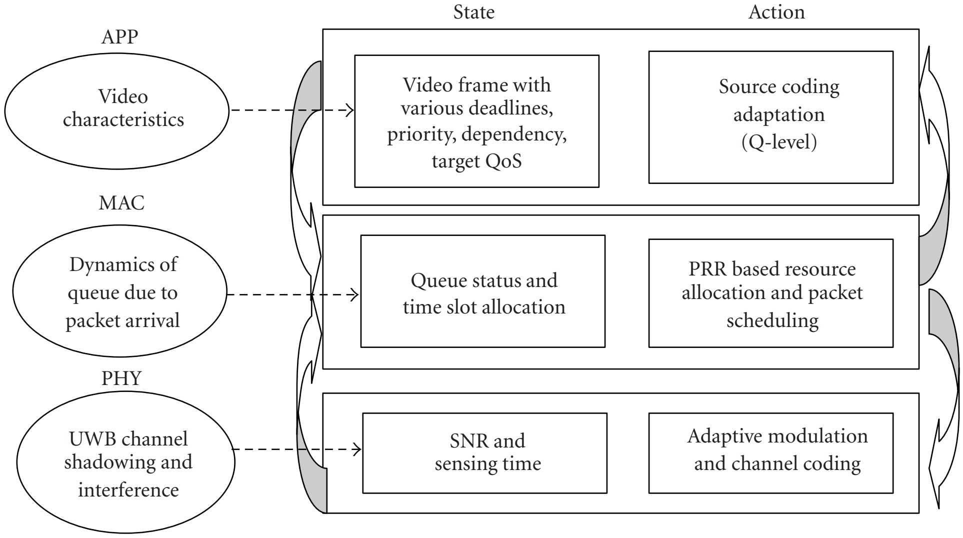

Figure 2: Proposed cross layer interactions.

path loss exponent (γ), equal 1.7, and shadowing (S) of 2.8 dB are used.

Assuming Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) UWB with channel bandwidth equal to 528 MHz and QPSK modulation technique is used, the bit error rate (BER) and energy per bit can be calculated directly. The probability of error in a packet of size L can be represented as [19]

$$\mathrm{PER}_1(L) = 1 - (1 - \mathrm{BER})^L. \quad (4)$$

Link layer retransmission is often used to combat channel error. If the retry limit is set to **n**, the probability of packet error after **n**-retry is [20]

$$\mathrm{PER}_2(L) = \left[1 - (1 - \mathrm{BER})^L\right]^{\mathbf{n}}. \quad (5)$$

From the PER, the job failure rate (JFR) which represents the performance quality at the APP layer can be derived as

$$\mathrm{JFR} = 1 - [1 - \mathrm{PER}_2(L)]^{\mathbf{m}} \quad (6)$$

with **m** being the number of video fragments.

As in [17], BER of 10^{-4} or 10^{-6}can be achieved when the SNR is greater than -3 dB and -1 dB, respectively. To achieve the target BER of 10^{-6}, the transmitter and receiver should be in a distance within 9 m from each other (refer to Figure 3). We consider a centralized topology with one of the C-UWB nodes acting as a central controller to manage the time slot allocation, data rate, and channel access. The central controller is also chosen as the common receiver. Thus, the other C-UWB nodes (assigned as transmitters) are placed uniformly around the central controller. Henceforth, the term C-UWB nodes and central controller are used to differentiate between transmitter and receiver.

The interactions between C-UWB transmitter and the central controller (common receiver) are depicted as in Figure 4. The figure also illustrates message exchange activity between the two entities in general. At the start of every GOP, C-UWB users trigger the central controller about its intention to perform local sensing. With the objective of achieving high opportunistic access to C-UWB and high protection to PU users, two cooperative sensing methods namely, AND and OR rule are compared in this paper. The C-UWB users report their sensing information to the central controller to be fused for the final decision of PU presence. Then, central controller calculates the optimal resource time slot allocation in accordance with the target and instantaneous PRR and BER. The target PRR and BER are set to 8% and 10^{-6}, respectively to meet the QoS requirement of multimedia application. In this paper, we assume that all C-UWB users transmit the same MPEG-4 video traffic with same target PRR and BER requirement.

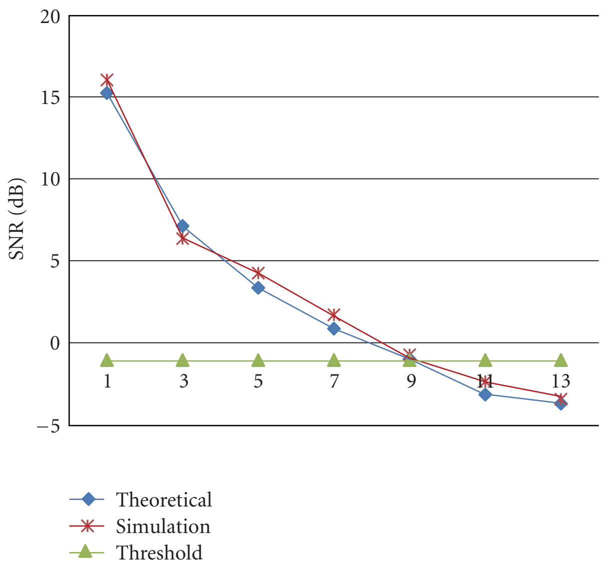

Figure 3: SNR performance versus distance [17].

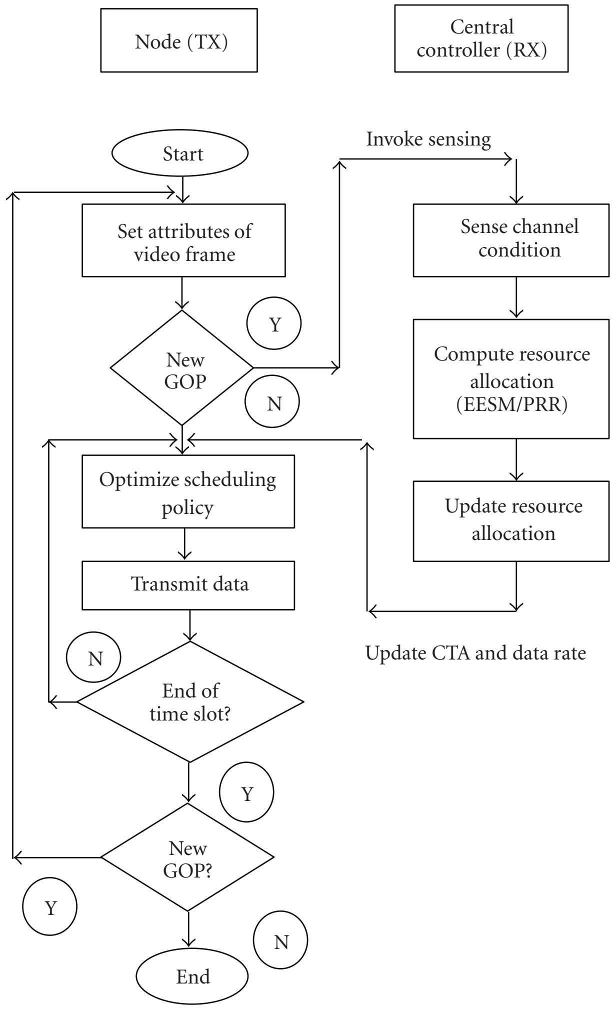

Figure 4: Interactions between C-UWB and central controller.

Thus, the central controller knows about the target QoS in advanced. However, the algorithm can be easily extended to multiple traffic-type with different target PRR and BER by sending the traffic type information during signal beaconing.

Consequently, the proposed algorithm eliminates the need of dedicated channel time slot request from the C-UWB nodes to the central controller. Thus, the central controller will directly announce the allocated time slots and optimal data rate without having to wait for channel time request from C-UWB nodes (transmitter). Then, packet transmission will be performed based on optimal scheduling policy that resides at the MAC layer of C-UWB device (transmitter). For simplicity, we adopt a round robin scheduling policy, which allows C-UWB nodes to take turn in transmitting their multimedia traffic. Although it is a round robin mechanism, the MAC scheduling is improved by assigning a different time slot allocation to each C-UWB nodes depending on their target and instantaneous PRR and BER, queue status, and channel conditions of all C-UWB nodes in the network. Each C-UWB user is also assigned with an optimal sensing time to meet the target probability of detection (P_d) and probability of false alarm (P_f) during worst case channel conditions. Thus, the MAC scheduling is considered optimal in terms of the sufficient sensing time and the time slot allocation.

In the next section, we will provide more insights of the sensing mechanisms and PRR-based resource allocations adopted in our cross-layer design.

3.2. Sensing Mechanisms. Probability of detection, P_d, and probability of false alarm, P_f, are the performance metrics used for spectrum sensing. Using energy detection scheme, the sensed signal of a CU, $X[n]$, has two hypotheses. Hypothesis H_0 is to denote the absence of PU, and hypothesis H_1 is for the presence of PU. Generally, these can be represented as [12, 21]

$$H_0 : X[n] = W[n], \quad H_1 : X[n] = W[n] + S[n], \tag{7}$$

where $n = 1, \ldots, N$; N is the number of samples. The noise $W[n]$ is assumed to be AWGN with zero mean and variance ${\sigma_w}^2$. $S[n]$ is the primary user's signal and is assumed to be a random Gaussian process with zero mean and variance ${\sigma_x}^2$.

The output of the energy detector, Y, which serves as decision statistic, is described by [12, 21]

$$Y = \sum_{n=1}^{N} (X[n])^2. \tag{8}$$

Comparing with a threshold, γ, and based on optimal decision yielded by the likelihood ratio Neyman-Pearson hypothesis testing [12, 21], P_d and P_f can now be defined as the probabilities that the CU's sensing algorithm detects a PU under H_0 and H_1, respectively.

$$P_f = P(Y > \gamma \mid H_0), \quad P_d = P(Y > \gamma \mid H_1). \tag{9}$$

Since we are interested in low SNR regime (SNR = ${\sigma_x}^2/{\sigma_w}^2$), large number of samples should be used.

Thus, we can use central limit theorem to approximate the decision statistic as Gaussian. Then

$$P_f = Q\left(\frac{\gamma - N\sigma_w^2}{\sqrt{2N\sigma_w^4}}\right), \tag{10}$$

$$P_d = Q\left(\frac{\gamma - N(\sigma_w^2 + \sigma_x^2)}{\sqrt{2N(\sigma_w^2 + \sigma_x^2)^2}}\right), \tag{11}$$

where $Q(\cdot)$ is the complementary distribution function of the standard Gaussian. Combining (10) and (11), P_d is derived to be

$$P_d = Q\left[\frac{Q^{-1}\left(P_f\right) - \mathrm{SNR}\sqrt{N/2}}{1 + \mathrm{SNR}}\right]. \tag{12}$$

Thus the number of samples needed for PU detection is

$$N = 2\left[\frac{Q^{-1}\left(P_f\right) - Q^{-1}(P_d)}{\mathrm{SNR}} - Q^{-1}(P_d)\right]^2. \tag{13}$$

It can be seen that in bad channel condition (low SNR), P_d is lower and the number of samples needed for PU detection increases, that is, the sensing time becomes longer. It is desirable to have a high P_d for better PU protection. Meanwhile, a low P_f is favorable for a better opportunistic access and higher achievable throughput for CU. Since these two magnitudes pose a trade-off on the sensing mechanism, an optimal sensing time needs to be determined such that some Quality of Service (QoS) is attained by both PU and CU.

It has been reported in [22] that cooperative spectrum sensing can greatly increase the probability of detection in fading channels. Multiple CUs can be coordinated to perform spectrum sensing cooperatively and the sensing information exchanged between neighbors is expected to have a better chance of detecting PU compared to individual sensing. A cooperative network of several CR-assisted systems can be modeled as an OR/AND-rule network.

In a cooperative spectrum sensing system using OR-rule, the PU is considered to be present if any of the cognitive radios detects the presence of the primary user. Assuming that there are M identical and independent cognitive radios in the cooperative spectrum sensing system, the cooperative probability of detection Q_d and probability of false alarm Q_f using OR-rule are given by [23]

$$Q_d = 1 - \prod_{i=1}^{M}(1 - P_{d,i}), \tag{14}$$

$$Q_f = 1 - \prod_{i=1}^{M}\left(1 - P_{f,i}\right), \tag{15}$$

where P_d and P_f are, respectively, the probability of detection and probability of false alarm of a stand-alone cognitive radio.

While in AND-rule fusion scheme, all collaborating CUs must declare the presence of PU for the final decision to be positive. The probabilities are presented as [23]

$$Q_d = \prod_{i=1}^{M} P_{d,i}, \tag{16}$$

$$Q_f = \prod_{i=1}^{M} P_{f,i}. \tag{17}$$

The performance of these cooperative sensing schemes will be compared to give an insight to the preferred one to be deployed.

3.3. PRR-Based Resource Allocation. PRR-based resource allocation is deployed at the central controller. Using exponential effective signal-to-noise ratio mapping (EESM) technique, a sequence of varying SNRs are mapped to a single value that is strongly correlated with the actual BER. Then, the estimated PER can be calculated directly using equation (5) and thus the PRR. In a case of MB-OFDM UWB, one channel is divided into three subbands and the allocation is made by a subband; that means each user is dynamically allocated one subband for the duration of one superframe. Hence, the effective SNR calculated for each subband is given by [24]

$$\text{SNR}_{\text{eff}} = -\lambda ln\left(\frac{1}{N_s}\sum_{i=1}^{N_s} e^{-\text{SNR}i/\lambda}\right). \tag{18}$$

λ is a scaling factor that depends on the selected modulation and coding scheme (MCS), N_s is the number of subcarriers in a subband, and SNR_i is the ratio of signal to interference and noise on the ith subcarrier. Knowing the target PRR (PRR_T) and the instantaneous PRR (PRR_i) of each user i, central controller will compute the optimal time slot allocation. It is worth to note that the resource allocation is computed for each super frame. Let'us denote K as superframe size, the PRR based resource allocation can be described as follows;

Input: PRR_{T1}, PRR_{T2}, PRR_1, PRR_2, K

Output: Channel time allocation reserved for user 1 (N_1) and user 2 (N_2)

Optimization Problem: How to increase the throughput of each user (meaning maximizing $N_1 + N_2$) while maintaining a target PRR.

Max ($N_1 + N_2$) subject to:

$$\begin{aligned} N_1\text{PRR}_1 &> \text{PRR}_{T1} \\ N_2\text{PRR}_2 &> \text{PRR}_{T2} \\ N_1 + N_2 &< K. \end{aligned} \tag{19}$$

Solving the problem using Lagrange optimization;

$$\begin{aligned} L = {} & (N_1 + N_2) + \alpha(\text{PRR}_{T1} - N_1\text{PRR}_1) \\ & + \beta(\text{PRR}_{T2} - \text{N}_2\text{PRR}_2) + \gamma(\text{N}_1 + \text{N}_2 - \text{K}) \end{aligned} \tag{20}$$

with α, β, γ being Lagrange multiplier. Derivatives of L set to zero yield;

$$\frac{\delta L}{\delta N_1} = 1 - \alpha\text{PRR}_1 \tag{21}$$

$$\frac{\delta L}{\delta N_2} = 1 - \beta\ \text{PRR}_2 \tag{22}$$

$$\frac{\delta L}{\delta \alpha} = \text{PRR}_{T1} - N_1\text{PRR}_1 \tag{23}$$

$$\frac{\delta L}{\delta \beta} = \text{PRR}_{T2} - N_2\text{PRR}_2 \tag{24}$$

$$\frac{\delta L}{\delta \gamma} = N_1 + N_2 - K. \tag{25}$$

Let's define the ratio of PRR targets of both users as;

$$a = \frac{\text{PRR}_{T2}}{\text{PRR}_{T1}}. \tag{26}$$

Thus;

$$N_1 = \frac{K^*(1 - \text{PRR}_2)}{(a^*(1 - \text{PRR}_1) + (1 - \text{PRR}_2))}, \quad (27)$$

$$N_2 = \frac{K^* a^*(1 - \text{PRR}_1)}{(a^*(1 - \text{PRR}_1) + (1 - \text{PRR}_2))}. \quad (28)$$

Using the same approach, the resource allocation can be extended to M-multi user case. For variable number of user M, we can approximately estimate each user i is allocated with;

$$M_i = \frac{K}{1 + \sum_{j=0}^{j=M} \text{PER}_i/\text{PER}_{j,j\neq i}}. \quad (29)$$

Based on equation (29), all users will be assigned optimal time slot in accordance to their own channel condition as well as other users channel conditions. This may leads to two extreme cases. The first case occurs when users that experienced very bad channel condition may not be granted with any time slot allocations during that one superframe duration. The second case is when the time slot allocation is dominated by one user that has a very good channel condition. To overcome this issue, number of packets in queue is also considered in the algorithm. If there is no packet in queue, the user will be granted the shortest time slot, just enough for queue update. When there are packets in queue, the user will be given enough time slots according to the number of packets in queue, but limited to the maximum allowable N_i. This to ensure that users are assigned with sufficient time slots according to number of packets in queue and subject to their channel condition. Additionally, the packet is also constrained with the delay deadline and retransmission limit. The packet is dropped if it is failed to be received by the central controller after the deadline expired.

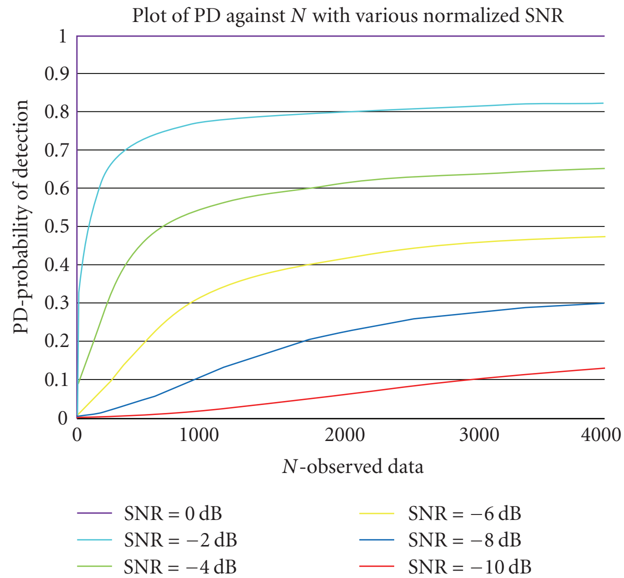

FIGURE 5: Probability of detection against number of sample for various SNR.

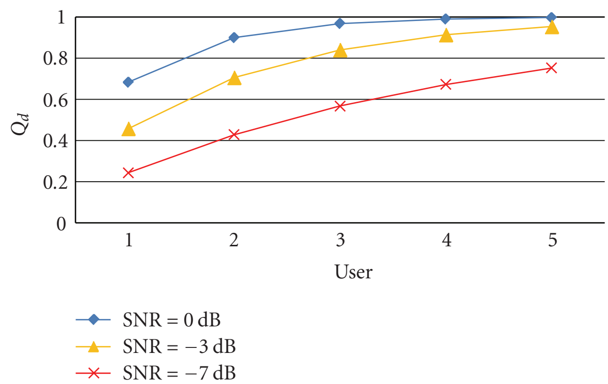

FIGURE 6: Performance of cooperative sensing using OR-rule.

4. Results and Analysis

In this section, simulation results of our proposed MAC-centric cross-layer design are presented. Simulations were carried out using MATLAB and Network Simulator 2 (NS-2).

Figure 5 shows that as SNR decreases, the number of samples needed to achieve the target P_d of 99.999% increases. That is longer sensing time is required to detect the presence of PU at lower SNR. Taking −6 dB as the worst case SNR for C-UWB, each user should be allocated approximately 1823 samples for sensing activity, which is translated into 14 μs of sensing time.

Figures 6 to 8 demonstrate the performance of OR-rule cooperative sensing in terms of probability of detection and probability of false alarm. It can be observed from Figure 6 that PU detection is greatly enhanced by OR-rule cooperative sensing as it improves the probability of detection under various SNR conditions. However, probability of false alarms also increases as shown in Figure 7 and hence, reduces the opportunistic access for CUs. Furthermore, under a bad SNR condition (−7 dB), there is basically no access allowed for CUs as the probability of false alarms approaches almost 100%. Therefore, it is recommended that opportunistic access for CUs is allowed only in good SNR condition. Since the probability of false alarms recorded by individual node is much lower than by cooperative sensing, it is also recommended that attempts of spectrum access is carried out based on local sensing rather than cooperation.

Figure 8 illustrates that the disadvantages of OR-rule cooperative sensing in terms of probability of false alarms can be significantly overcome by using more samples for detection and hence, longer sensing time. In the case of the set P_d is 90%, for all 5 users and bad SNR condition of −6 dB, a target Q_f of about 10% can be achieved by using sample size of 400.

The performance of AND-rule fusion scheme at the central controller is demonstrated in Figures 9 to 11. As expected, the results proved to be contradictory to that of OR-rule. This scheme is more advantageous to CUs as it reduces PU protection (Figure 9) and offers more chances for the channel to be reused, thus higher achievable throughput

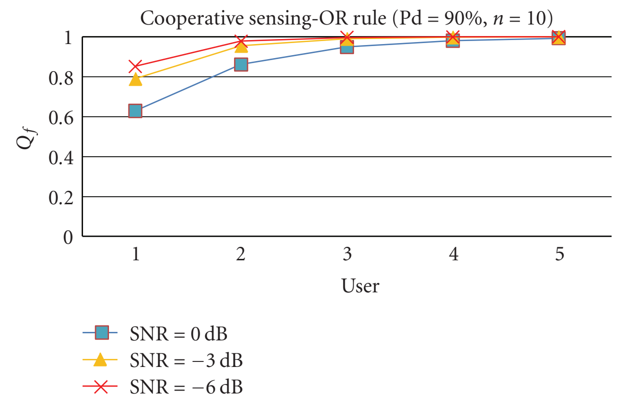

Figure 7: Performance of probability of false alarm using OR-rule cooperative sensing under various SNR conditions.

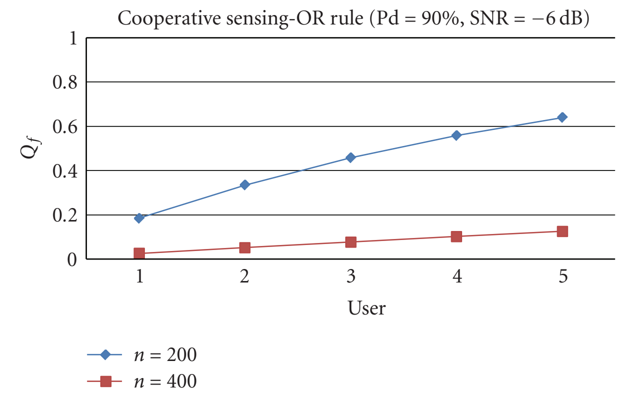

Figure 8: Performance of probability of false alarm using OR-rule cooperative sensing under various SNR conditions.

Table 1: Simulation Parameter.

Parameter (unit)	Value
Video input	(a) Foreman.qcif (b) Time Expand Sampling (TES) video traffic model
Superframe size (μsec)	1-65536 (dynamic)
Packet size	2000 Byte
Basic Rate	22 Mbps
PHY header time	15 μsec
MAC header	16 Bytes
HCS	2 Bytes
FCS	4 Bytes
SIFS	10 μsec
IP/UDP/RTP header	48 Bytes
GOP size	9
Dead line	1/30 sec
Retry limit	3

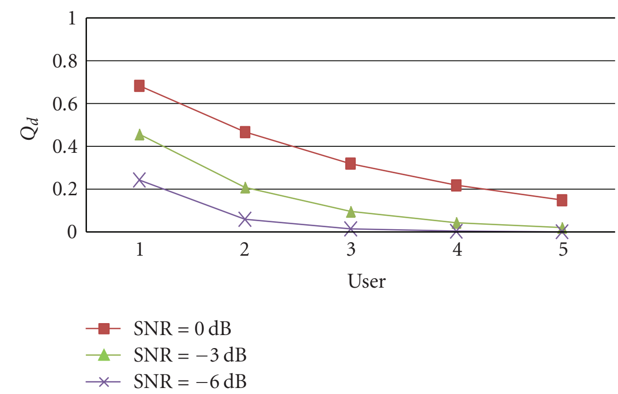

Figure 9: Performance of cooperative sensing using AND-rule.

for SUs as collaboration greatly decreases the probability of false alarm (Figure 10). In the case of bad SNR condition of −6 dB, as of OR-rule fusion scheme, more samples are needed, hence longer sensing time, to achieve the target of low P_f, that is, 10% as shown in Figure 11.

To evaluate the impact of sensing activity (and thus additional delay) to multimedia application, simulations were carried out using the 'Foreman' video sample and each user is allocated 14 μsec to perform local energy sensing. Table 1 shows the simulation parameters used.

JFR was used as performance metric to represent how many packets were lost as compared to the whole packets generated. Packet loss may be due to delay deadline or corrupted during transmission. Figure 12 depicts that the video quality degrades when sensing activity is included at the MAC superframe. Interestingly, the quality degradation is quite minimal because the ratio of sensing period to superframe size is small. In short, C-UWB users are more aware of the channel conditions and hence can be more adaptive without significant overhead.

Figure 13 shows the video performance in terms of average JFR when our cross layer design approach that is aware of the dynamic channel condition, queue and APP layer QoS target was implemented. We compare our cross layer design approach with the non-cross layer design (non-CLD) approach and cross layer design that is insensitive to queue (CLD-queue insensitive). In the non-CLD case, each user is assigned with fix amount of time slot all the time regardless of their instantaneous channel conditions as well as the QoS requirement set by the APP layer. In contrast, CLD-queue insensitive approach is adaptive to channel conditions but ignore the queue status. In other words, C-UWB nodes may be assigned with large amount of time slot allocations (due to their good channel condition) but yet has not many packets in the queue. Thus, wasteful of resources allocation may occur.

From Figure 13, we note that our proposed cross layer design outperformed the non-CLD and CLD-queue insensitive. However, the non-CLD performs better when more than 8 users share the limited resources. This is due to the fact that when more users are competing, the user that experiences bad channel condition will always get the minimum timeslot as compared to the fix timeslot allocation. Although the JFR is higher when more users are involved in the resource sharing, we observed that the received video

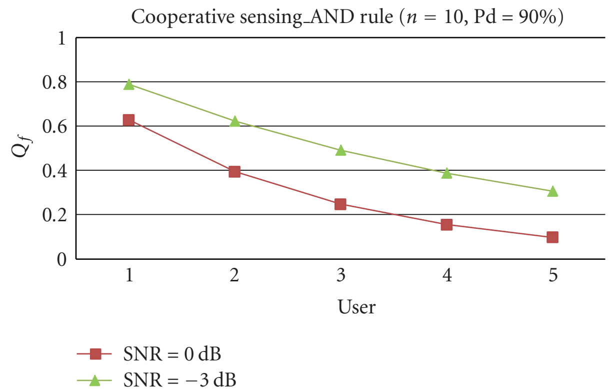

FIGURE 10: Performance of probability of false alarm using AND-rule cooperative sensing under various SNR conditions.

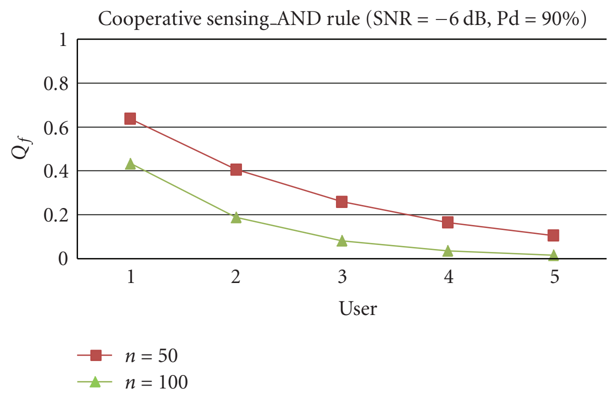

FIGURE 11: Performance of probability of false alarm using AND-rule cooperative sensing at different sample sizes.

quality is improved for users with quite stable and good channel conditions to compensate with users that experience very bad channel conditions.

5. Conclusion

By considering the findings in the preliminary investigation, SNR is considered as the main QoS metric at the PHY layer to determine the appropriate sensing time for cognitive users in our cross layer design. We propose that optimal time slot for optimal resource allocation to be assigned for sensing activity and data transmission at the MAC layer. The impact of sensing activity is minimal on the multimedia delivery and hence offer better cross layer strategy through PRR based resource allocations. We also recommend that cooperative sensing is implemented as it enhances decision making by collaborating CUs. OR-rule data fusion scheme is favored as from the comparison, it offers better PU protection. The proposed cross layer design will be further improved by considering the heterogeneous video traffic characteristics.

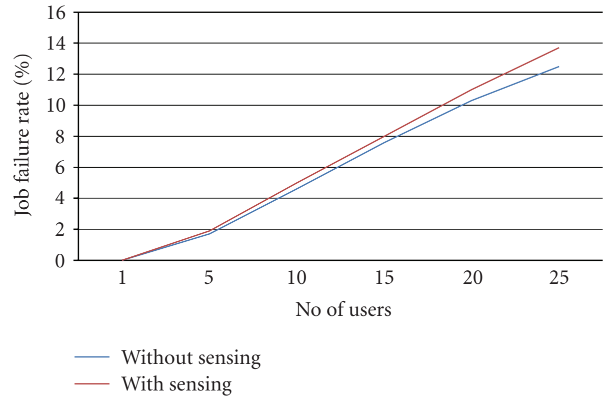

FIGURE 12: Impact of sensing period to MPEG-4 video transmission.

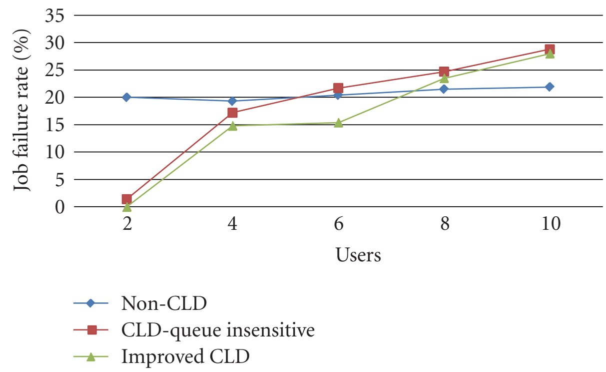

FIGURE 13: Average video quality.

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