An Adaptive Opportunistic Transmission for Unlicensed Spectrum Sharing in Heterogeneous Networks

Daehyoung Kim, Pervez Khan, Hoon Kim

Abstract—Efficient utilization of spectrum resources is a fundamental issue of wireless communications due to its scarcity. To improve the efficiency of spectrum utilization, the spectrum sharing for unlicensed bands is being regarded as one of key technologies in the next generation wireless networks. A number of schemes such as Listen-Before-Talk(LBT) and carrier sensor adaptive transmission (CSAT) have been suggested from this aspect, but more efficient sharing schemes are required for improving spectrum utilization efficiency. This work considers an opportunistic transmission approach and a dynamic Contention Window (CW) adjustment scheme for LTE-U users sharing the unlicensed spectrum with Wi-Fi, in order to enhance the overall system throughput. The decision criteria for the dynamic adjustment of CW are based on the collision evaluation, derived from the collision probability of the system. The overall performance can be improved due to the adaptive adjustment of the CW. Simulation results show that our proposed scheme outperforms the Distributed Coordination Function (DCF) mechanism of IEEE 802.11 MAC.

Keywords—Spectrum sharing, adaptive opportunistic transmission, unlicensed bands, heterogeneous networks.

I. Introduction

DUE to the surge in usage of smart devices, there is an ever increasing demand for spectrum. Therefore, efficient utilization of spectrum resources is a fundamental issue of wireless communications due to its scarcity. To improve the efficiency of spectrum utilization, the spectrum sharing for unlicensed bands is being regarded as one of key technologies in the next generation wireless networks. The unlicensed bands, such as the ones used in 2.4GHz ISM (Industrial, Scientific and Medical) and 5GHz U-NII (Unlicensed National Information Infrastructure), used for a number of access technologies such as 802.11 (WiFi), 802.15.1 (Bluetooth) and 802.15.4 (ZigBee), have traditionally been unsuitable for use with access technologies designed primarily to operate in licensed frequencies, like LTE, that focus on maximizing spectral efficiency and optimizing user experience. Some collaborative operations such as data offload in unlicensed band today is primarily carried out using Wi-Fi which is designed in the premise of trading off performance for low cost and simple implementation for spectrum sharing. Meanwhile, an advanced scenario of unlicensed spectrum usage of LTE features such as Carrier Aggregation (CA) has made it possible to operate these technologies in unlicensed bands as well. From the user perspective, this means an enhanced broadband experience, higher data rates, seamless use of both licensed and unlicensed bands, with high reliability and robust mobility through licensed anchor carrier. A critical element of the design for LTE in unlicensed band is to ensure LTE-U (LTE in Unlicensed band) co-exists with current access technologies such as Wi-Fi on fair and friendly bases [1]. A number of schemes such as LBT and carrier sensing adaptive transmission (CSAT) have been suggested from this aspect [2], [3], [4]. Those schemes might be useful for spectrum sharing between LTE and Wi-Fi, but more efficient sharing schemes are required for improving spectrum utilization efficiency.

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This work considers an opportunistic transmission approach and a dynamic CW adjustment scheme for LTE-U users sharing the unlicensed spectrum with Wi-Fi, in order to enhance the overall system throughput. The decision criteria for the dynamic adjustment of CW is based on the collision evaluation, derived from the collision probability of the system. The overall performance can be improved due to the adaptive adjustment of the CW. Simulation results show that our proposed scheme outperforms the DCF mechanism, especially in dense environments.

The remainder of this paper is structured as follows: Section II presents the system model of the opportunistic transmission and dynamic CW adjustment scheme. Section III addresses the numerical results and conclusions appear in Section IV.

II. System Model

As shown in Fig. 1, we assume that there is an LTE-U Access Point (AP) in the coverage of a Wi-Fi AP. The Wi-Fi AP can only use the unlicensed band, while the LTE-U can use both the licensed and unlicensed bands to serve n Wi-Fi and n LTE-U users, respectively. The DCF mechanism is also adopted in the LTE-U AP to enable the LTE-U users to compete each other and with the Wi-Fi users for the unlicensed band.

A. DCF Mechanism

According to the IEEE 802.11 DCF mechanism, all the stations compete for an unlicensed channel based on binary exponential backoff scheme with the minimum CW size (CW_{min}), and the maximum CW size (CW_{max}), is adopted in the Wi-Fi AP. Fig. 3 shows the basic DCF mechanism of the IEEE 802.11 MAC protocol. From [5], the stationary

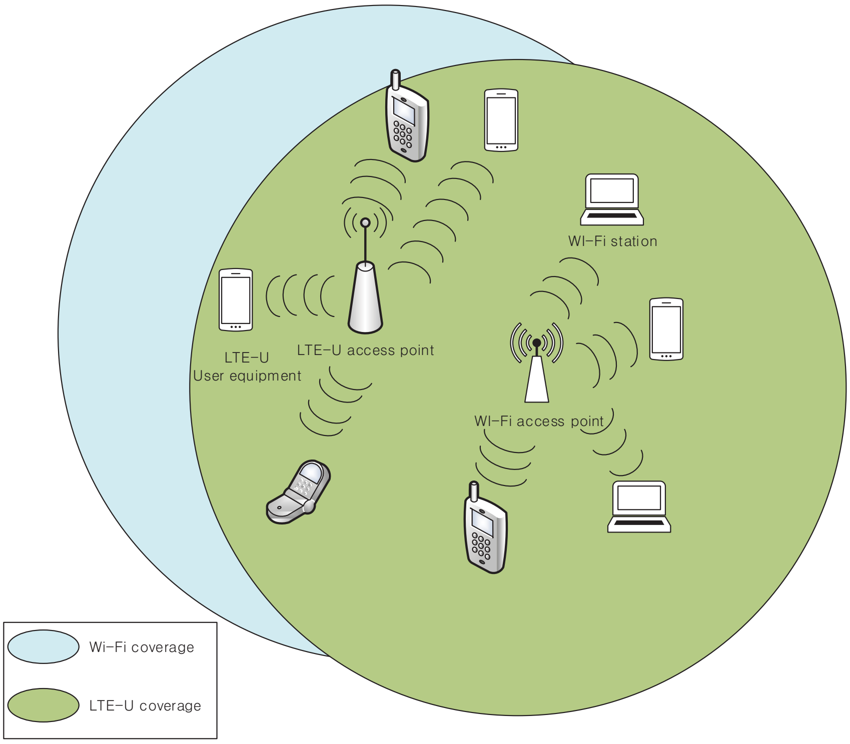

Fig. 1 LTE-U and Wi-Fi co-existence in the unlicensed-band

probability that a node transmits in a generic slot can be written as

$$\beta = \frac{2 \times (1-2\gamma)}{(1-2\gamma)(W_D+1)+\gamma W_D(1-(2\gamma)^{mD})} \quad (1)$$

Let τ be the stationary probability that LTE-U users transmit a packet in a generic slot of the unlicensed band and can be expressed as

$$\tau = \frac{2 \times (1-2\hat{\gamma})}{(1-2\hat{\gamma})(W_L+1)+\hat{\gamma} W_L(1-(2\hat{\gamma})^{mL}} \quad (2)$$

where γ and $\hat{\gamma}$ are the collision probability of the DCF users and LTE-U users, respectively, and can be expressed as:

$$\gamma = 1-(1-\tau)(1-\beta)^{n-1} \quad (3)$$

$$\hat{\gamma} = 1-(1-\tau)^{n} \quad (4)$$

B. The Proposed Scheme

Fig. 2 illustrates an adaptive opportunistic transmission scheme for LTE-U in the Licensed/Unlicensed Bands. This scheme first monitor the available channels for unlicensed opportunistic transmission. The main aim of the scheme is to optimize the CW for LTE-U users based on the channel collision evaluations being formulated in (4). If the collision threshold is reached, then the CW is optimized accordingly followed by the DCF mechanism showed in Fig. 2. The CW bounds, CW_{min} and CW_{max} for LTE-U and Wi-Fi users are mentioned in Table I.

C. Performance Metric

Let η be the system throughput, defined as the fraction of time for which the medium is used to successfully transmit payload bits [6]. It can be presented as

$$\eta = \frac{P_{tr} P_s (1-\gamma) T_{payload}}{E_s} \quad (5)$$

where $T_{payload}$ is the mean payload duration. P_{tr} is the probability that there is at least one transmission in the given time slot of unlicensed spectrum, P_{tr} is computed by

$$P_{tr} = 1-(1-\beta)^{n}(1-\tau) \quad (6)$$

P_s is the probability of success and can be computed as

$$P_s = \frac{n\beta(1-\beta)^{n-1}(1-\tau)}{P_{tr}} \quad (7)$$

E_s be the expected time spent per state of the Markov chain [5], by a tagged station. E_s is computed as:

$$E_{state} = (1-P_{tr}).\delta + P_{tr}.(1-\gamma).T_s + P_{tr}.\gamma.T_c \quad (8)$$

δ is the length of a CSMA slot mentioned in the standard. T_s and T_c be the average busy period for a successful and a colliding transmission, respectively. T_s and T_c can be computed as

$$\begin{aligned} T_s &= T_{(MAC+PHY)overhead} + T_{Payload} + T_{DIFS} \\ &\quad + T_{SIFS} + T_{ACK} \quad (9) \\ T_c &= T_{(MAC+PHY)overhead} + T_{Payload} + T_{DIFS} \end{aligned}$$

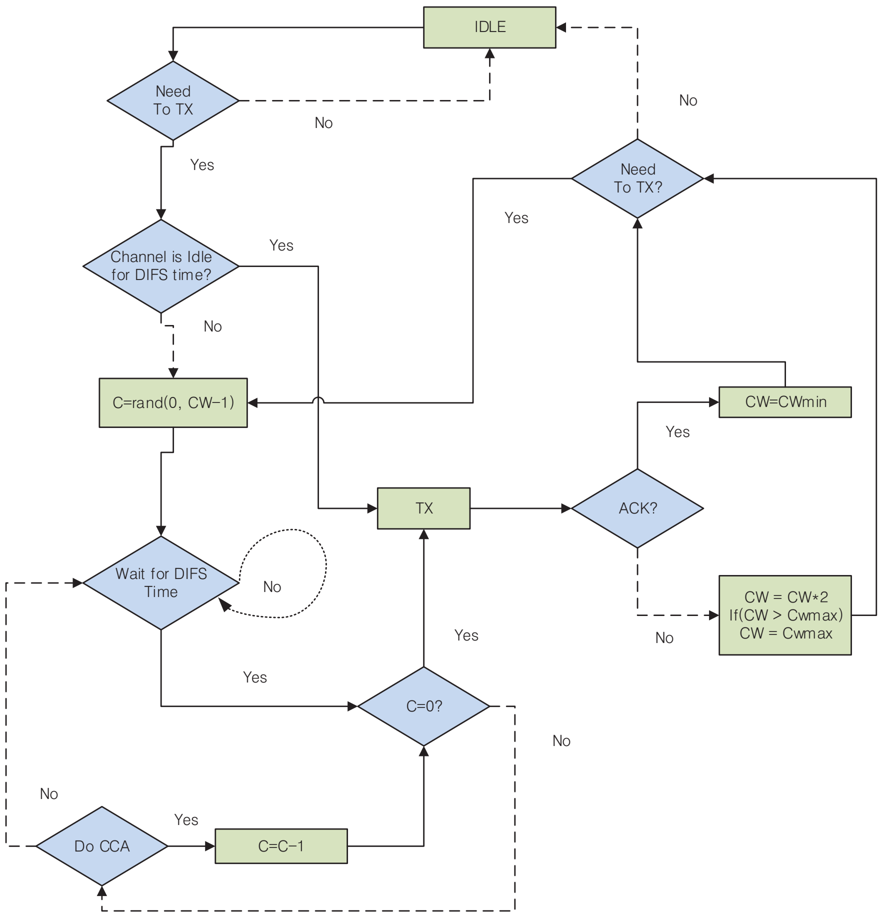

Fig. 2 DCF of IEEE 802.11 MAC protocol

Similarly, let $\hat{P}_s$ be the successful transmission probability of LTE-U users while competing with the Wi-Fi Users and is given by

$$\hat{P}_s = \frac{\tau(1-\beta)^n}{P_{tr}} \tag{10}$$

III. Analytical Results

Both LTE-U users and Wi-Fi users are deployed in an unlicensed networks area in equal proportion. Analytical results are generated in MATLAB by considering LTE-U and Wi-Fi parameters as described in Table I. The CW is of variable length, and The selection of CW should be in such a way that, it should improve the overall system throughput. As the proposed scheme considers the load on a channel through channel collision evaluation using (4) and thus dynamically adjust the CW, which consequently reduces the collision and hence improve the overall system throughput. Fig. 4 shows the normalized system throughput of the LTE-U users and Wi-Fi users in a co-existing scenario of unlicensed band. We assume that both LTE-U and Wi-Fi users are in equal proportion and share the same unlicensed spectrum. Due to the adaptive adjustment of CW, from Fig. 4, we can see that our proposed scheme outperforms the DCF mechanism of IEEE 802.11 MAC.

TABLE I
Simulation Parameters

Parameters	Values
$MACProtocol$	DCF
$DCFPacketPayload$	12000 bits
$DIFS$	34μs
$SIFS$	16μs
ACK	336bits
$Slottime$	20μs
$Wi-Fibitrate$	300Mbps
$CW_{min}(LTE-U, Wi-Fi)$	15
$CW_{max}(LTE-U, Wi-Fi)$	1023
$TXOPlimit$	2ms
$MACHeaderofDCFPacket$	192bits
$PHYHeaderofWi-Fi$	224bits
$LTE-UDataRate$	15Mbps
$Collisionprobabilitythreshold$	0.35
$Unlicensedbandwidth$	20MHz

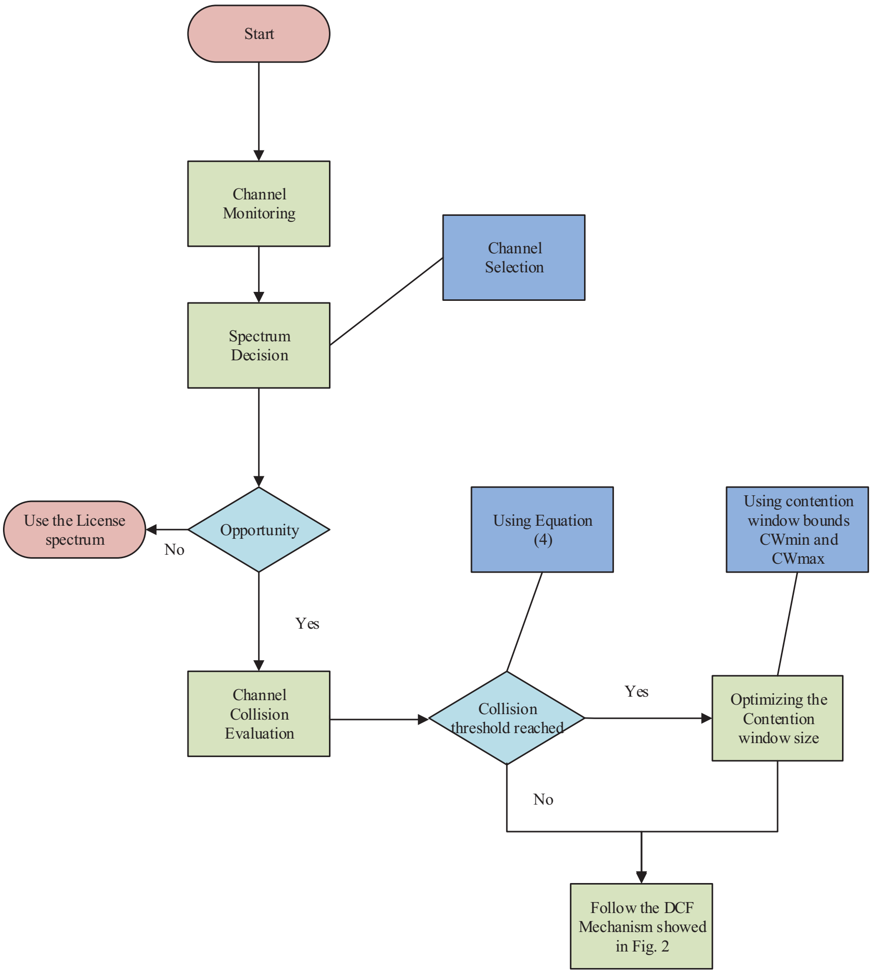

Fig. 3 The Proposed Scheme

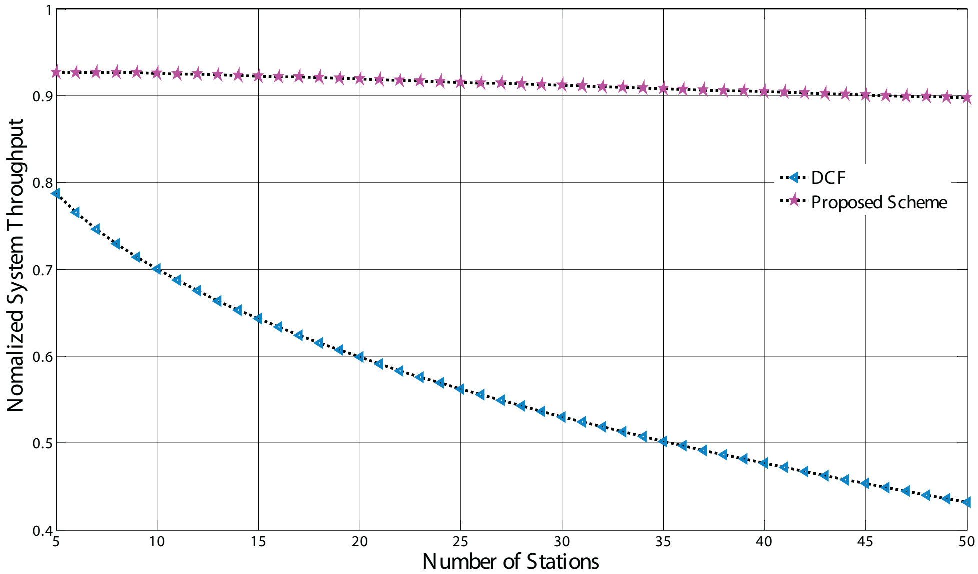

Fig. 4 Normalised system throughput of the unlicensed band

IV. Conclusion

In this paper, we have developed an opportunistic transmission and a dynamic CW adjustment scheme for LTE-U users sharing the unlicensed spectrum with Wi-Fi, in order to enhance the overall system throughput. The decision criteria for the dynamic adjustment of CW is based on the collision evaluation, derived from the collision probability of the system. The overall performance can be improved Due to the adaptive adjustment of the CW. Simulation results show that our proposed scheme is more consistent and outperforms the DCF mechanism of IEEE 802.11 MAC, especially in dense environment.

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