Enhanced Listen-before-talk Scheme for Frequency Reuse of Licensed-assisted Access Using LTE

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***Abstract*—Licensed-Assisted Access (LAA) using Long Term Evolution (LTE) is a promising solution to alleviate the problem of scarce spectrum resources by extending to the unlicensed band. However, co-existence mechanisms should be carefully taken into consideration to provide fair co-existence to other LAA and 802.11 based Wi-Fi networks that operate on the same unlicensed carrier. In this paper, we focus on the design of listen-before-talk (LBT) for the LAA system and provide insights into the impact of LAA clear channel assessment (CCA) threshold on the trade-off between frequency reuse and interference avoidance. Moreover, an enhanced LBT scheme is proposed by adaptively adjusting the LAA CCA threshold to exploit the benefits of frequency reuse for LAA while guaranteeing the fair co-existence with Wi-Fi at the same time. System-level simulation is performed to analyze the CCA threshold among LAA networks and evaluate the effectiveness of the proposed LBT scheme compared to that with fixed CCA threshold. It is shown that significant performance gains can be achieved for LAA by using the proposed LBT scheme under efficient protection of Wi-Fi performance.**

Keywords*—*LAA, unlicensed spectrum, frequency reuse, clear channel assessment, co-existence.

I. Introduction

Driven by the proliferation of fast developing wireless devices and bandwidth-greedy applications, the wireless data traffic has been dramatically growing in recent years. To meet the unrelenting demand of mobile services especially in indoor and hotspot scenarios, substantial spectral efficiency technologies have been investigated by Long Term Evolution (LTE) and beyond systems [1], yet the capacity is restricted to be further improved due to the lack of available spectrum resources. A promising solution to overcome the scarcity of spectrum is to expand to the unlicensed spectrum in, e.g., 5GHz band, where more than 600MHz has been assigned or currently planned to be assigned [2]. Carrier aggregation can be employed to integrate the unlicensed spectrum into the overall LTE system, where unlicensed carriers can be operated as secondary cells (Scells) to offload some best effort traffic at the assistance of the primary cell (Pcell) in existing licensed spectrum which is dedicated to serve the delay-sensitive traffics and provide seamless coverage [3].

To evaluate the benefits resulting from the efficient utilization of unlicensed spectrum and investigate potential solutions to the challenging issues, the feasibility study on Licensed-Assisted Access (LAA) using LTE has been approved for Release 13 [4] in Third-Generation Partnership Project (3GPP) RAN 65 meeting. One target for the design of LAA using LTE, or called LAA for short, is to derive a single global framework to satisfy the regulatory requirements over various countries and regions, including maximum transmission power restriction, dynamic frequency selection (DFS) for radar avoidance, maximum channel occupancy duration, etc.

Moreover, co-existence problem is also an essential challenge which should be taken careful consideration since the unlicensed carrier may be shared not only by LAA small cells of the same operator but also by those deployed without site planning, including inter-operator small cells as well as other radio access technologies (RATs) such as Wi-Fi based on IEEE 802.11 a/n/ac [5]–[8]. As the major incumbent system on 5GHz band, Wi-Fi applies carrier sense multiple access with collision avoidance (CSMA/CA) mechanism in the media access control (MAC) protocol, which can effectively avoid aggressive interference especially in dense deployment. In order to provide fair co-existence with other LAA small cells and the widely deployed Wi-Fi networks, it is preferable for LAA to adopt listen-before-talk (LBT) mechanism similar as Wi-Fi, where clear channel assessment (CCA) procedure is applied before data transmission. Simulation is carried out in [5] to evaluate the co-existence of 802.11n and time division duplex (TDD) based LAA on unlicensed spectrum. In addition, the impacts of channel propagation as well as different TDD configurations to both Wi-Fi and LAA performances are analyzed. Muting scheme is applied for LAA to protect the Wi-Fi network in [6] and [7], where the Evolved Node B (eNB) of LAA silences partial subframes to reduce the degradation to the co-existing Wi-Fi network. The effectiveness of LBT is evaluated in [8] together with static muting and other sensing-based schemes. By analyzing the simulation results it shows that using such channel sensing schemes achieves a balance between the LAA and Wi-Fi systems. To our best knowledge, however, there is little literature focusing on the impact of CCA threshold to the co-existence of LAA.

In this paper, we present two candidate LBT implementations for LAA, frame based equipment (FBE) and load based equipment (LBE). In addition, the impact of CCA threshold on LAA frequency reuse and interference is analyzed. To improve the LAA throughput and at the same time guarantee the fair co-existence with Wi-Fi, an enhanced LBT scheme is proposed, by which CCA threshold is adaptively adjusted to balance the channel access opportunity and interference avoidance. System-level simulation is performed for indoor and outdoor deployments over various traffic loads to evaluate the impact of different CCA thresholds and the effect of the proposed scheme. It is illustrated that remarkable performance can be achieved in terms of both average and edge user throughput by configuring an appropriate CCA threshold for the co-existence among LAA networks. In addition, significant gains can be observed for LAA by adopting the proposed scheme with slight impact to the co-existing Wi-Fi network. The transmission of LAA on unlicensed spectrum can be supplementary downlink (SDL) mode where only downlink transmission is allowed, or TDD mode where both downlink and uplink transmissions are supported. SDL has been considered with high priority in 3GPP standardization under current discussion [4]. To this end, we only focus on the evaluation for SDL while leave TDD for future work.

II. CO-EXISTENCE MECHANISMS

To avoid causing serious interference and provide fair channel utilization, the discussion of co-existence mechanisms has to be prioritized for LAA. One candidate is to adopt almost blank subframes (ABS) introduced in Release 10, which requires the eNB to statically mute partial subframes [6]. Although ABS can reuse the legacy system with little impact to standardization, long period of muting and active of LAA may cause large delay for LAA and neighboring Wi-Fi, respectively, which is detrimental for the real-time traffics. On the other hand, by using static ABS pattern it is difficult to balance the channel access opportunities between LAA and Wi-Fi for various deployments and traffic loads; e.g., smaller proportion of muted subframes is preferable if the Wi-Fi network is sparsely deployed, while larger proportion of muted subframes may be beneficial for dense deployment to protect Wi-Fi.

Another channel sharing candidate is the LBT mechanism, where each transmitter has to perform channel sensing prior to data transmission. The channel can be occupied only when it is sensed as idle and has to be relinquished after a maximum continuous occupancy time. By using LBT, the eNB can more dynamically occupy the channel based on the detected medium status, which both alleviates the delay issue and effectively balances the channel occupancy among co-existing transmitters. Furthermore, LBT mechanism can comply with the regulatory requirements mandated in some certain regions, e.g. Europe and Japan.

A. CCA procedures for LAA

FBE and LBE required by Europe regulation [9] are two candidate LBT solutions which can be potentially adopted by LAA to provide a single global framework [10].

For FBE, a *Fixed Frame Period* is defined, which consists of *Channel Occupancy Time* and *Idle Period* as depicted in Fig. 1 (a). Before starting transmissions on the medium, the transmitter shall perform a CCA check towards the end of the *Idle Period*. If the medium is considered as busy during the CCA slot of at least 20 μs, the transmitter shall not transmit on that channel during the next *Fixed Frame Period*. Otherwise the transmitter can continuously occupy the medium during the next *Channel Occupancy Time* with a maximum time of 10ms. The major advantage of FBE is the convenient user equipment (UE) detection. The CCA is performed always at the end of the *Fixed Frame Period* so that the detection complexity of UEs can be greatly decreased since only the 1st OFDM symbol of each subframe have to be blindly detected to confirm the potential start of a downlink burst.

For LBE, the transmitter shall perform a CCA check before a burst of transmission on the medium as depicted in Fig. 1

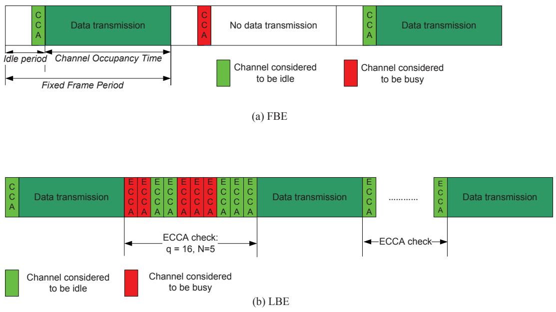


Fig. 1. FBE based and LBE based channel sensing mechanisms.

(b). The transmitter can immediately occupy this channel if the medium is considered to be idle during the CCA slot of ($\geq$ 20 μs); otherwise an extended CCA (ECCA) check shall be applied based on a back-off strategy which is similar as the CSMA/CA mechanism. The value of back-off counter N is randomly generated for each ECCA check in the range 1 to q, where q is declared by the manufacturer in the range of [4, 32]. The counter N is decremented by 1 every time the medium is considered to be idle during an ECCA slot ($\geq$ 20 μs). When N reaches to zero the transmitter can occupy the channel with a maximum time of $13/32 \times q$ ms. In contrast with FBE, the time of capturing the channel may be in the middle of the subframe, resulting in the complexity and power consumption for UEs to blindly detect the start of the eNB transmission. However, LBE takes advantages over FBE in channel access opportunities especially in high load scenarios because the transmitter can continuously detect the channel if one CCA/ECCA slot fails to capture the channel instead of waiting for a long *Fixed Frame Period* like FBE does.

B. Impact of CCA threshold on co-existence

The CCA check defined in 802.11 specifications include CCA based on energy detection (CCA-ED) and CCA based on carrier sense (CCA-CS). The channel is considered to be busy if the total sensed power during the CCA slot exceeds the CCA-ED threshold of -62dBm (20MHz), or the measured power of another access point (AP) or station in preamble detection exceeds the CCA-CS threshold of -82dBm (20MHz) [5]. In contrast, only CCA-ED is mandated in [9], thus in this paper we only consider the design of CCA-ED for the LAA LBT mechanism.

By adjusting the CCA threshold, the trade-off can be achieved between frequency reuse and interference avoidance. E.g., as shown in Fig. 2, increasing the CCA threshold reduces the sensing range of the two neighboring eNBs performing the CCA check, which provides possibility of simultaneous transmission. On the other hand, this aggressive channel reuse is at the expense of introducing potentially increased interference. The scheduled UEs will be negatively impacted if they are close to the simultaneous transmitting interferer as depicted in Fig. 2 (b), while the network performance will be significantly improved if the introduced interference is slight as depicted in Fig. 2 (c) or the system can still provide robust transmission under increased interference.

Compared with Wi-Fi, LTE can better live with interference due to its robust physical layer (PHY) design, including HARQ, enhanced inter-cell interference coordination (eICIC),

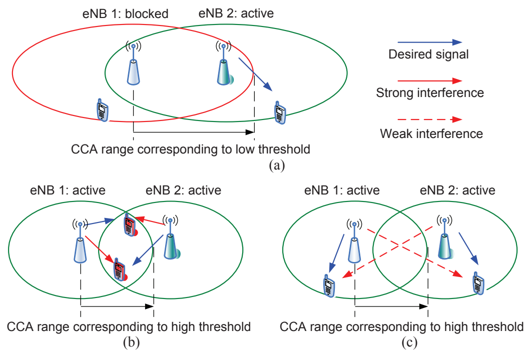


Fig. 2. Impact of CCA threshold on frequency reuse and interference of eNBs operating on unlicensed spectrum.

adaptive modulation and coding (AMC), interference rejection combining (IRC), etc, as well as the assistance of licensed spectrum, thus LAA with a high CCA threshold may benefit from frequency reuse when co-existing with other LAA cells of at least the same operator. In addition, the CCA threshold should be carefully configured to ensure at least LAA does not impact Wi-Fi services more than an additional Wi-Fi network on the same carrier.

C. Adaptive LBT scheme for LAA

Although configuring a fixed CCA threshold for generic LAA system is easily implemented in practical networks, it is difficult to provide significant gains for LAA while at the same time provide friendly channel sharing with Wi-Fi over various deployments. In this paper we propose an enhanced LBT scheme to adaptively adjust the CCA threshold of LAA to provide significant enhancement for LAA while on the other hand protect the Wi-Fi networks which are more vulnerable to interference. This investigation may technically conduct the regulation for CCA threshold and provide guidance for regions without mandatory CCA threshold requirements.

Under the proposed scheme, the CCA threshold TL is dynamically adjusted before the CCA/ECCA check by every LAA eNB following the procedure shown in Fig. 3. To avoid causing adverse impact to neighboring APs/stations, TL is initialized as a lower bound LB and kept unchanged if any Wi-Fi signal above LB is detected in previous CCA/ECCA checks. Wi-Fi preamble detection can be introduced to facilitate LAA system recognizing the existence of Wi-Fi network.

The interference caused by LAA eNBs of the same operator is more slight due to reference signal received power (RSRP) based cell association so that capacity gains can be achieved under aggressive reuse even for densely deployed intra-operator small cells. Denoting the detected power from eNB j of the same operator as P_j^{intra}, the sensing eNB can subtract the strong receive power (e.g., $P_j^{\text{intra}} > LB$) from the total received power, or equivalently add TL with P_j^{intra}.

The interference from inter-operator LAA eNBs may be more severe due to the absence of RSRP based association and interference coordination techniques. Considering the tolerance of introduced interference may be different for the scheduled UEs with different locations as demonstrated in Fig. 2 (b), (c), TL should be be further adjusted taking into account the measured inter-operator interference fed back by the scheduled UE. Denoting $\Delta P_u = P_u^k - \max_i\{P_u^i\}$ as the received power gap between the serving eNB k and the strongest inter-operator interfering eNB i for the scheduled UE u, TL is increased if all UEs in scheduling set $\mathcal{U}$ are not severely impacted, e.g., $\max_{u\in\mathcal{U}}\{\Delta P_u\} > 0$ dB, and keep unchanged otherwise.

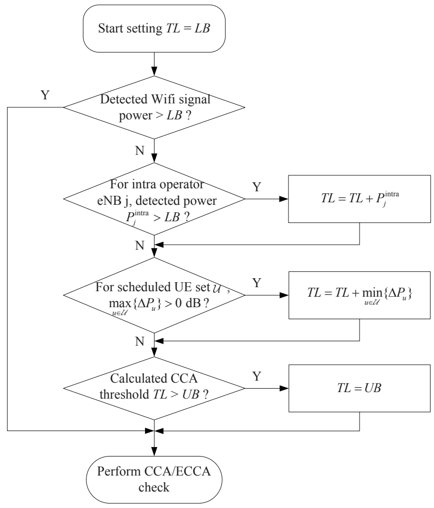


Fig. 3. Procedure of the adaptive CCA threshold adjustment scheme.

At last, an upper bound UB is assumed to ensure TL is adjusted within the range of $[LB, UB]$.

III. Performance Evaluation

In this section the system-level simulation is implemented to evaluate the performances of LAA and Wi-Fi downlink transmission for both indoor deployment and outdoor deployment and analyze the effectiveness of the proposed scheme.

A. Simulation assumptions

The cellular network is composed of 7 macro cells (21 sectors) which operate only on licensed spectrum. One cluster (outdoor)/building (indoor) is randomly deployed per sector. Two operators A and B share 1 carrier with 20MHz bandwidth in 5.8GHz unlicensed band. 4 small cell eNBs/APs per operator are uniformly located within per cluster for outdoor deployment and are deterministically located within per building for indoor deployment as shown in Fig. 4. 10 UEs per operator are randomly deployed within the cluster/building and associated to the small cell eNBs/APs based on intra-operator RSRP criterion. 3GPP FTP model 3 is adopted with 0.5MB file size and various Poisson based packet arrival rates λ. Three co-existence scenarios are simulated, including:

- Scenario 1: Wi-Fi network of operator A co-exists with another Wi-Fi network of operator B.

- Scenario 2: Wi-Fi network of operator A co-exists with LAA network of operator B.

- Scenario 3: LAA network of operator A co-exists with another LAA network of operator B.

The default parameters in the simulation can refer to the current 3GPP discussions in [11] unless otherwise stated.

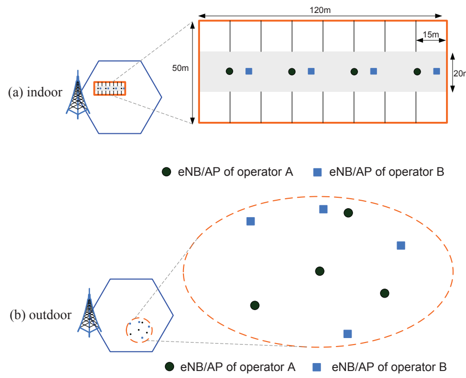


Fig. 4. Indoor and outdoor deployment scenarios.

Besides, some additional selected assumptions are given in Table I.

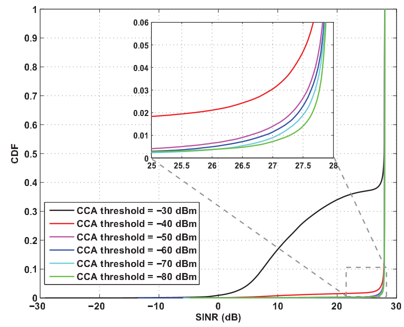
TABLE I. PARAMETER ASSUMPTIONS

Parameters	LAA Value	Wi-Fi Value
Bandwidth	20MHz	
Tx power (E.I.R.P)	23 dBm	
Tx mode	2Tx-2Rx single stream transmission	
Traffic model	FTP model 3 with 0.5 MB file size	
MCS	Up to 256QAM	Up to 256QAM, LPDC coding
LBT mechanism	LBE	CSMA/CA
CCA-ED	[-80 dBm, -30 dBm]	-62 dBm
CCA-CS	N/A	-82 dBm
CCA backoff window	q = 32	[15, 1023]
CCA slot length	24 μs	9 μs
HARQ	Num of max retrans = 3	N/A
Link adaptation	AMC	Open loop
LB	-70 dBm	N/A
UB	-40 dBm	N/A
Scheduling	Proportional fair (PF)	Round robin (RR)

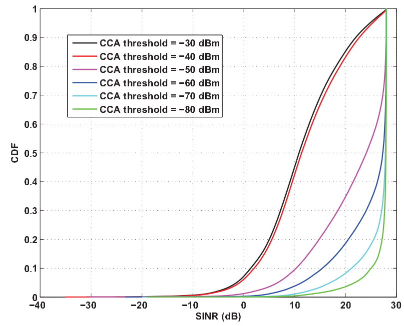
B. Impact of CCA threshold for LAA-LAA co-existence

We first analyze the impact of the fixed CCA thresholds to LAA performances when co-existing with another LAA network in Scenario 3. The cumulative density function (CDF) of downlink signal to interference plus noise (SINR) curves for LAA network are shown in Fig. 5 (a) and (b) for indoor deployment and outdoor deployment, respectively. It is observed that the SINR is decreased with the increase of CCA threshold, which is due to the increased frequency reuse. However, the SINR is not drastically impacted when CCA threshold is in the low region, e.g. $<$ -40 dBm for indoor deployment. Consequently an relatively aggressive CCA threshold is encouraged to be configured for indoor without causing significant effect to the reliability of downlink transmission. On the other hand, the indoor SINR is severely degraded when the CCA threshold increases from -40 dBm to -30 dBm because the two closest eNBs, which are the dominant interferers to each other as depicted in Fig. 4 (a), are enabled to simultaneously transmit under such high threshold. For outdoor scenario, the SINR is smoothly decreased with the increase of CCA threshold since the eNBs/APs are uniformly deployed, but the SINR curves for -40 dBm and -30 dBm are nearly overlapped because the LAA network almost achieves reuse 1 under both thresholds.

Fig. 6 plots the served throughput per cell with various traffic loads. It can be seen that the throughput is improved



(a) indoor

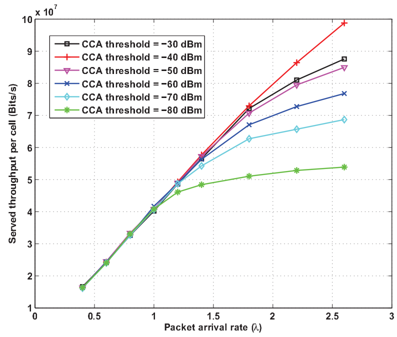


(b) outdoor

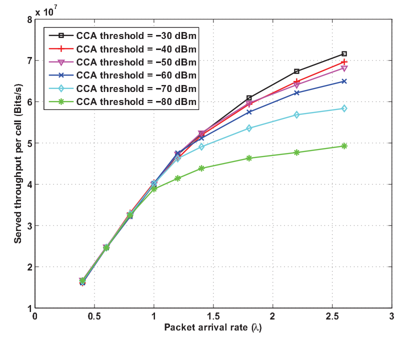
Fig. 5. Downlink SINR CDF for Scenario 3 indoor and outdoor deployments over various CCA thresholds.

when the CCA threshold increases from -80 dBm to -40 dBm for both indoor and outdoor because of the efficient channel utilization despite the degradation of SINR. As a consequence, LAA may exploit capacity gains by allowing a more aggressive channel reuse with an acceptable increase of interference by configuring a higher CCA threshold than Wi-Fi CCA-ED value. But the served throughput is impaired in high load scenarios for indoor deployment when the CCA threshold increases from -40 dBm to -30 dBm due to the severe degradation of SINR. Therefore, the CCA threshold, if configured fixedly, should be carefully considered based on the practical deployment.

The user experiences can be revealed by Fig. 7 and Fig. 8 in terms of average user perceived throughput (UPT) and 10-percentile UPT, respectively. It is shown that the performance of both average UPT and 10% UPT over various packet arrival rates can be improved with an appropriate increase of CCA threshold, e.g. from -80 dBm to -50 dBm. However, persistently increasing the CCA threshold to a considerably high value of e.g., -30 dBm leads to performance loss especially for the edge users at high load scenarios. An optimal CCA threshold can be preferred considering the trade-off between frequency reuse and interference, e.g., -40 dBm for indoor deployment. This optimal CCA threshold may be different in different scenarios, so it is suggested to adaptively adjust the CCA threshold on the basis of the deployment scenario and traffic load to achieve best performance.



(a) indoor



(b) outdoor

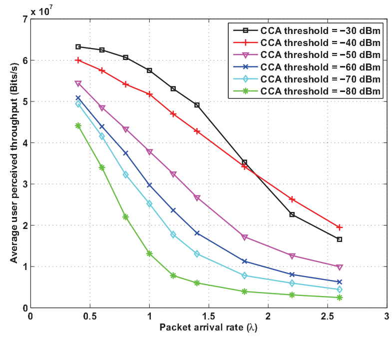
Fig. 6. Served throughput per cell for Scenario 3 indoor and outdoor deployments over various CCA thresholds.

C. Adaptive LBT scheme for co-existence of LAA-LAA and LAA-Wi-Fi

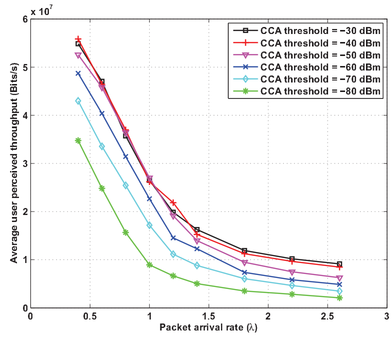
The UPT performances of the proposed adaptive LBT scheme is evaluated and compared with that of the fixed CCA threshold of -70 dBm as shown in Fig. 9 - Fig. 12. Both the performances of LAA-LAA in Scenario 3 and LAA-Wi-Fi Scenario 2 are simulated to evaluate the co-existence performance and the impact of the proposed scheme to LAA and Wi-Fi; in addition, Wi-Fi-Wi-Fi in Scenario 1 performance is also given as a reference.

The UPT performances of Wi-Fi co-existing with a LAA network outperforms that co-existing with another Wi-Fi network under both fixed -70 dBm CCA threshold and the proposed scheme, from which we can conclude that LAA is a good neighbor to Wi-Fi. This is partly because the Wi-Fi network can be provided with more transmission opportunities considering the more relaxed CCA-ED threshold when co-existing with LAA than CCA-CS threshold when co-existing with another Wi-Fi network. In addition, high-efficient PHY design of LTE system can reduce the transmission time compared to 802.11 under the same traffic load. Then the occupancy time by LAA can be reduced to allow the co-existing Wi-Fi network to have more chances to access the channel.

Furthermore, both average UPT and 10% UPT of the victim Wi-Fi network is similarly impacted by the co-existing LAA network adopting the fixed CCA threshold with that adopting

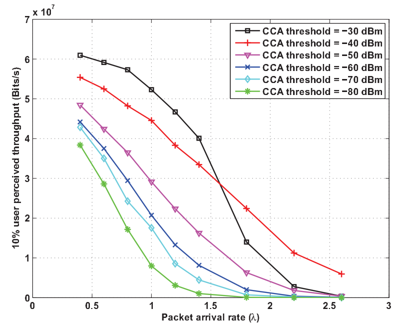


(a) indoor

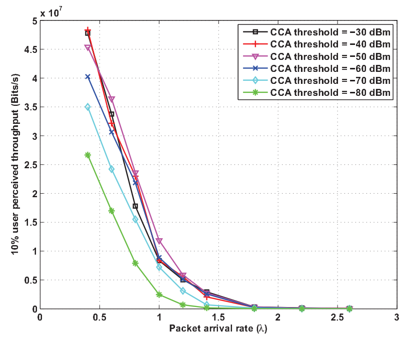


(b) outdoor

Fig. 7. Average UPT for Scenario 3 indoor and outdoor deployments over various CCA thresholds.



(a) indoor



(b) outdoor

Fig. 8. 10% UPT for Scenario 3 indoor and outdoor deployments over various CCA thresholds.

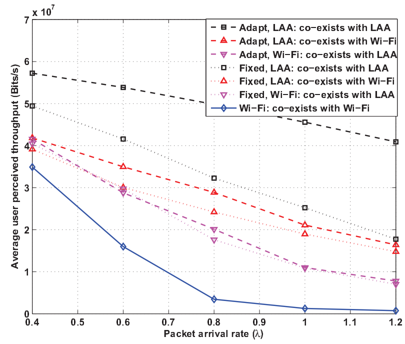


Fig. 9. Average UPT of the proposed LBT scheme for Scenario 2 and 3 under indoor deployment with Scenario 1 as a reference.

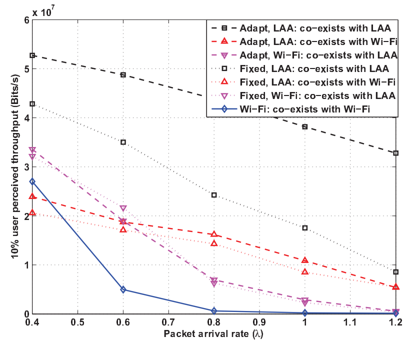


Fig. 10. 10% UPT of the proposed LBT scheme for Scenario 2 and 3 under indoor deployment with Scenario 1 as a reference.

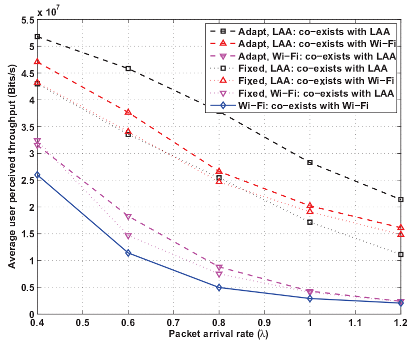


Fig. 11. Average UPT of the proposed LBT scheme for Scenario 2 and 3 under outdoor deployment with Scenario 1 as a reference.

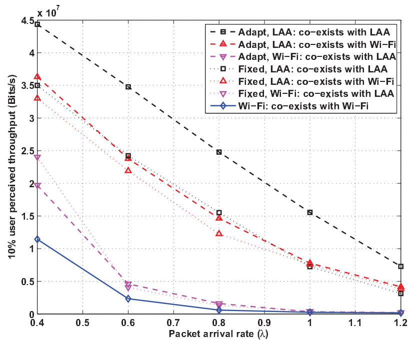


Fig. 12. 10% UPT of the proposed LBT scheme for Scenario 2 and 3 under outdoor deployment with Scenario 1 as a reference.

the adaptive CCA threshold adjustment scheme. The Wi-Fi network is even better protected by LAA network based on the adaptive scheme in high load scenarios because simultaneous transmission of LAA reduces the time of occupying the channel and thus alleviates the interference to Wi-Fi. On the basis of providing fair channel sharing with co-existing Wi-Fi performance, the proposed scheme achieves remarkable improvement in terms of LAA performances as compared to the fixed scheme for both LAA-Wi-Fi co-existence and LAA-LAA co-existence scenarios.

IV. Conclusions

In this paper we investigated candidate LBT mechanisms for LAA which operates on unlicensed spectrum and looked into the role of CCA threshold in balancing the frequency reuse among LAA small cells and interference avoidance to co-existing networks. In addition, we proposed an enhanced LBT scheme to develop capacity gains of LAA while guaranteeing Wi-Fi performance by adaptively adjusting the CCA threshold. Simulations are implemented to evaluate the co-existence of LAA-Wi-Fi, LAA-LAA and Wi-Fi-Wi-Fi in indoor and outdoor deployments. According to the simulation results, LAA capacity gains can be obtained by allowing a more aggressive reuse with an acceptable increase of interference by configuring a moderately high CCA threshold. Moreover, in contrast with that configured with fixed CCA threshold, the proposed LBT scheme can obtain obvious benefits for LAA under peaceful co-existence with Wi-Fi.

References

[1] M. Peng, Y. Li, J. Jiang, J. Li, and C. Wang, “Heterogeneous cloud radio access networks: a new perspective for enhancing spectral and energy efficiencies,” *IEEE Wireless Commun.*, vol. 21, no. 6, pp. 126-135, Dec. 2014.

[2] Huawei, “U-LTE: Unlicensed spectrum utilization of LTE,” white paper, Feb. 2014.

[3] F. Liu, E. Bala, E. Erkip, M. C. Beluri and R. Yang, ”Small cell traffic balancing over licensed and unlicensed bands,” to appear, *IEEE Trans. Veh. Technol.*

[4] RP-141646, “Study on Licensed-Assisted Access using LTE,” RAN 65, Sep. 2014.

[5] N. Rupasinghe and I. Guvenc, “Licensed-assisted access for WiFi-LTE coexistence in the unlicensed spectrum,” in *Proc. Global Commun. Conf. (GLOBECOM’14)*, Dec. 2014, pp. 894-899.

[6] F. M. Abinader, E. P. L. Almeida, F. S. Chaves, A. M. Cavalcante, R. D. Vieira, R. C. D. Paiva, A. M. Sobrinho, S. Choudhury, E. Tuomaala, K. Doppler, and V. A. Sousa, “Enabling the coexistence of LTE and Wi-Fi in unlicensed bands,” *IEEE Commun. Mag.*, vol. 52, no. 11, pp. 54-61, Nov. 2014.

[7] T. Nihtilä, V. Tykhomyrov, O. Alanen, M. A. Uusitalo, A. Sorri, M. Moisio, S. Iraji, R. Ratasuk, and N. Mangalvedhe, “System performance of LTE and IEEE 802.11 coexisting on a shared frequency band,” in *Proc. IEEE Wireless Commun. Networking Conf. (WCNC’13)*, Apr. 2013, pp. 1038-1043.

[8] J. Jeon, H. Niu, Q. C. Li, A. Papathanassiou, and G. Wu , “LTE in the unlicensed spectrum: evaluating coexistence mechanisms,” in *Proc. Global Commun. Conf. (GLOBECOM’14)*, Dec. 2014, pp. 740-745.

[9] ETSI EN 301.893 v1.7.1, “Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN,” 2012.

[10] R1-150978, “Description of candidate LBT schemes,” Huawei, HiSilicon, Mar. 2015.

[11] 3GPP TR 36.889 v0.3.1, Study on licensed-assisted access to unlicensed spectrum, 2015.