Transmit Power Control and Clear Channel Assessment in LAA Networks

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***Abstract*— Unlicensed LTE system holds high potential to effectively offload data traffic/video traffic from the crowded LTE networks. Listen-before-talk is generally necessary for unlicensed LTE to coexist with existing transmissions in the unlicensed band (e.g. wireless LAN). This paper studies static and dynamic clear channel assessment, static and dynamic transmit power control in unlicensed LTE systems.**

***Keywords*—Transmit Power Control; Clear Channel Assessment; IEEE 802.11; Wireless LAN; Unlicensed LTE; License Assisted Access**

I. Introduction

With smart phones and internet of things gaining more and more popular use, there is a significant spectrum shortage in the near future. To support the ever increasing demand, people are looking at many different ways, including higher frequency spectrum (e.g. millimeter wave frequency band), more spectrum efficient transmission technologies (e.g. massive MIMO), and more efficient use of the unlicensed spectrum. It is expected that more and more unlicensed spectrum may be allocated in the near future. The spectrum efficiency of LTE is generally larger than that of current WiFi systems, with the former 4 times more efficient reportedly [1]. This motivates more efficient use of the unlicensed band. One possibility is to redefine the IEEE 802.11 specifications to enable more efficient spectrum efficiency, e.g. the IEEE 802.11ax specification that is being developed. Another possibility is to introduce the LTE technologies into the unlicensed band, the so-called license-assisted access (LAA).

We give a brief introduction of unlicensed LTE in Section II. In particular, we consider two important techniques in unlicensed LTE: transmit power control (TPC) which dictates how loud one can talk, and clear channel assessment (CCA) which dictates how hard one should listen before talk. For clear channel assessment, we study two variants, i.e. static CCA where each station within the network sets a common, static CCA value regardless of the pathloss with reference to the serving eNodeB, and dynamic CCA where each station within the network sets a different CCA value, which may be determined by the pathloss with reference to the serving eNodeB. For transmit power control, we also study two variants, i.e. static TPC where each STA sets a fixed, common transmit power level regardless of the pathloss, and dynamic TPC where each STA sets a different transmit power level, which may be determined by the pathloss. In section III, we present a system level evaluation methodology in evaluating and optimizing the LTE-U network throughput performance. Numerical simulation results are presented in IV. Conclusions are drawn in section V.

II. License Assisted Access (LAA)

A. *License Assisted Access (LAA)*

A practical way to use LTE in unlicensed band is the Licensed Assisted Access (LAA), where two component carriers are used, with the primary carrier carrying LTE signals in the licensed band as usual, while the secondary carrier (in the unlicensed band) is taken advantage of in an opportunistic manner. In this case, the primary carrier is always on while the secondary (unlicensed) carrier could be on and off depending on channel availability. An LTE macro base station may be used to cover a larger range, covering multiple small cell stations, while each small cell is equipped with a LAA access point. This is illustrated in Figure 1.

An important technique to enable peaceful coexistence of LAA with existing technologies (e.g.

WiFi) is LBT: listen-before-talk. Basically, an LAA transmitter needs to listen the wireless medium (in the unlicensed band) to determine if it can transmit. If the channel is busy, then the transmitter should refrain from transmitting. Otherwise, any existing transmissions (e.g. by any existing WiFi devices or by other LAA devices) may be severely interfered. If the channel is empty, then the transmitter may proceed and transmit over the unlicensed band. Similar technologies have been used in IEEE 802.11 already.

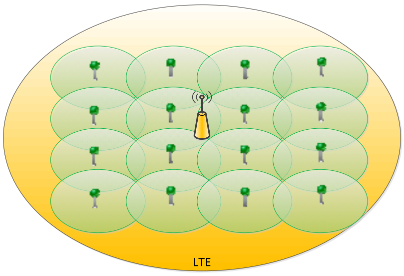

Figure 1. LTE macro cells and LAA small cells.

B. *Static Clear Channel Assessment*

In the IEEE 802.11 domain, the listen-before-talk feature is also known as clear channel assessment and two types of clear channel assessment (CCA) techniques may be used, energy based CCA and preamble based CCA. Because preamble based CCA is tightly linked to the preamble format of IEEE 802.11, we consider only energy based CCA here for simplicity. For *Energy based CCA:* the transmitter need to measure the total received power within the signal bandwidth, which is a non-coherent operation and does not require the transmitter to have any knowledge of the signal structure or packet format. In IEEE 802.11, the transmitter shall declare the channel as busy when the total received power is larger than -62 dBm in a 20 MHz band.

The CCA mechanism essentially serves as the ear of an LAA transmitter. By setting the CCA threshold to a small value, the transmitter is very sensitive to existing communications, even if the transmitter of an ongoing transmission is far away. Thus, any transmitter would have a less chance to transmit. On the other hand, by setting the CCA threshold to a high value, the transmitter is more aggressive in transmitting its own data, ignoring faraway transmitters and only paying attention to nearby transmitters. As a result, any transmitter would have a higher chance to transmit. In a LAA cell, it may be possible to set the same, static CCA value for all mobile stations. This is known as *static CCA* strategy, and has been adopted in IEEE 802.11.

C. *Dynamic Clear Channel Assessment*

Another possible way to set the CCA value is to link the CCA value with the reference received signal power [9]. This may be achieved by letting the mobile station to monitor a periodic or semi-periodic beacon signal sent from the serving mobile station.

A mobile station with a high reference signal power from the serving LAA base station would more likely be a cell center user and less chance to collide with other users, and thus could have a high CCA value and be more aggressive in accessing the unlicensed spectrum. On the other hand, a mobile station with a low reference signal power from the serving LAA base station (hence a cell edge user) would more likely be a cell edge user and more chance to collide with other users, and thus could have a low CCA value and be more conservative in accessing the unlicensed spectrum. This is known as dynamic CCA strategy and is being discussed in IEEE 802.11ax standardization.

One argument for static CCA is that, all the users within the same network would have the same opportunity to access the channel medium and is thus more fair. The counter argument is that, by setting a static CCA value to all stations far or near, the cell edge users, having a poorer channel condition and higher collision chance, is unfairly compensated and drags low the entire network throughput.

D. *Transmit Power Control*

Each transmitter may use a certain transmit power. Ideally, the transmitter may set its transmit power adaptively depending on the path loss between the transmitter and the receiver. This is known as *dynamic transmit power control*. In practice, such a dynamic transmit power setting may be unreliable, because the interference level in an unlicensed band may change frequently. Signaling cost may not be negligible especially for small packet transfer. Typically most WiFi transmitters use a fixed transmit power all the time.

Similar fixed transmit power strategy may be used in LAA systems as well. This is known as *static transmit power control.* Setting he transmit power controls how loud an LAA transmitter talks in occupying the wireless medium. By setting the transmit power to a small value (e.g. 10 dBm), only nearby users are able to hear the ongoing transmission, and faraway users, not hearing it, may proceed to transmitting their own data. As a result, other users generally have a larger chance to transmit. By setting the transmit power to a large value (e.g. 20 dBm), not only nearby users but also far-away users are able to hear the ongoing transmission and should refrain themselves from transmitting their own data. As a result, other users generally have a smaller chance to transmit.

Properly setting the CCA parameter and transmit power of its cell is of great importance. In the following we perform a numerical evaluation of the system and study the interaction of CCA and TPC in LAA networks.

III. Evaluation Methodology

A. *Simulation Setup*

For simplicity, we consider 16 rooms, with each room being 10 meters wide, 10 meters long and 3 meters high. The 16 rooms form a large square, as illustrated in Figure 1, with 4 rows and each row has 4 rooms. Each room is equipped with a LAA small cell base station, placed in the room center at the ceiling. For each room, four LAA mobile stations are placed uniformly randomly in the room, with a height as large as 2 meters and as small as 0 meters and uniformly distributed in-between. It is assumed each LAA mobile station is served by the LAA base station in the same room. A carrier frequency of 5.2 GHz is used for all LAA base stations. Unless explicitly mentioned, a frequency reuse 3 is used while each LAA base station chooses randomly one out of three 20MHz band to operate. This models the case where the frequency reuse is unmanaged. In another case, the frequency reuse may also be carefully managed such that spatial separation in the same frequency band is as large as possible.

Indoor channel type B, as defined in IEEE 802.11ac channel model [4] is used, which includes not only path loss, log-normal shadow fading, as well as multipath channel fading. Such a channel model is mostly suited for small indoor rooms. As each room is separated by walls, wall penetration loss is considered and assumed to be 14dB per wall [2]. For two rooms on the diagonal, a separation of two walls is assumed, leading to 28 dB penetration losses. Noise power is calculated using room temperature and a 5dB noise figure is assumed. We consider only uplink transmissions, e.g. all data traffic are originated from mobile stations to LAA small cell base stations. A full buffer traffic pattern is assumed. It is mandated that all LAA mobile stations use the same static CCA and TPC parameter as specified by their serving base stations.

B. *Evaluation Strategy*

The numerical evaluation is done for multiple drops, while for each drop, the mobile station positions are randomly generated and keep unchanged, the path loss between the transmitters (and interferers) and receivers are calculated accordingly, and then the shadow fading are randomly generated and keep unchanged. For each drop, multiple realizations (or events) are simulated. Each event corresponds to a set of links (with each link having one transmitter and one receiver) communicating at the same time while satisfying the CCA constraint and transmit power constraint in a specific order. The set of concurring links and the specific order vary from one event to another, modeling the random channel access behavior. For each drop, each event, the following steps are taken to model the CCA and TPC mechanisms in accessing the channel:

1. *Initial link insertion*

   Randomly select a room. Select the LAA base station and randomly select a LAA mobile station from the room. In the uplink case, the LAA mobile station is the transmitter and the LAA base station is the receiver. In the downlink case, the reverse is used. For the particular link in consideration, calculate the path loss, generate the random shadow fading and the random multipath fading according to the channel model. Mark this room as visited.

2. *Adding new links*

   Randomly select another room from the list of rooms that have not been visited. Similarly, select the LAA base station and randomly select a LAA mobile station within the room. In the uplink case, the LAA mobile station is the transmitter and the LAA base station is the receiver. In the downlink case, the reverse is used.

   The potential new transmitter needs to perform clear channel assessment to determine if the link should be activated. In particular, the potential new transmitter should measure the *total received power* from all activated transmitters (which are potential interferers). If the total received power at the potential new transmitter is larger than the CCA threshold, the potential new link should not be activated. Otherwise, the potential new link should be activated, and the associated transmitter should be marked as activated as well. No matter what, the room should be marked as visited. This step is then repeated until all the rooms in the system have been visited. Note that for a network with *N* LAA base stations, at most *N* links can be activated at the same time.

3. SINR and throughput calculation

At this step, all the rooms are marked, with certain links (and associated transmitters/receivers) activated. For each activated receiver, we then calculate the received SINR considering the signal component from its own transmitter, and interference from all other activated transmitters. For example, with n activated links, each receiver has one serving link and n-1 interfering links. The received SINR is then mapped to an achievable throughput over the link, while the mapping is performed using a MCS (modulation and coding) lookup table. Typically, the MCS table may be generated from link level simulations. For each realization (or event), the achievable throughput summed across all activated links are measured.

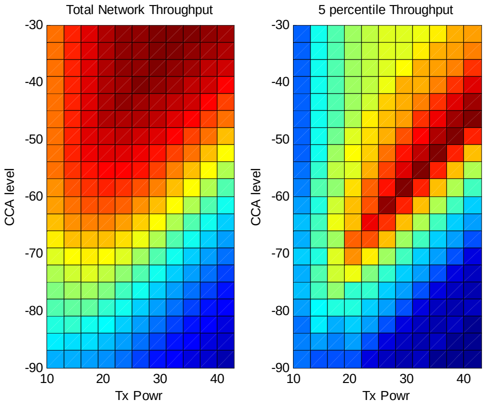

Figure 2 Static CCA and TPC.

Also, for each drop, as we repeat for multiple events, some stations may be active (and thus has throughput) for this event, but may be inactive (and thus has no throughput) for the next event. Thus, for each station, we may define the per-user throughput averaged across all events and all drops. The purpose to look at the per-user throughput is to investigate how the user throughput is distributed. One important metric to look at is the 5-percentile throughput, which reflects to some degree of system fairness to all served users.

IV. Numerical Results

A. Static CCA and TPC

Figure 2 presents the total network throughput as well as the 5-percentile user throughput, for different static CCA levels and static TPC levels, where dark red color means high throughput, while light blue color means low throughput in general. Frequency reuse factor of 1 is used. On the x-axis, transmit power is varied from 10 dBm to 43 dBm. On the y-axis, clear channel assessment level is varied from -90 dBm to -30 dBm.

In general, increasing the CCA level helps boost the total network throughput, but saturates beyond a certain point. On the other hand, increasing the CCA level helps boost the 5-percentile throughput initially, but becomes detrimental beyond a certain point. In general, the static CCA level should not be too large, as it may create overly aggressive transmitters.

Increasing the static transmit power level helps boost the total network throughput initially, but yields negative gains beyond a certain point. Same applies when 5-percentile throughput is concerned. In general, transmit power should not be too large, as it may create overly aggressive/lousy transmitter. It may not satisfy the power limitations in the unlicensed band either.

An interesting observation can be made regarding the 5-percentile throughput. Note that there exists a linear relationship (in the dB domain) between the optimal CCA level and optimal transmit power level: a -60dBm static CCA level coupled with a 25 dBm static transmit power level may provide similar performance as a -50 dBm static CCA level coupled with a 35 dBm static transmit power level. This may be very beneficial in practical wireless network planning.

B. Dynamic CCA and TPC

Figure 3 presents the total network throughput as well as the 5-percentile user throughput, when dynamic CCA and TPC are used. The transmit power margin (in dB) is essentially proportional to the target

SNR, a higher transmit power margin translates to a higher target SNR. On the other hand, the CCA level margin is chosen based on the reference received signal power, measured with reference to the serving base station and without interference.

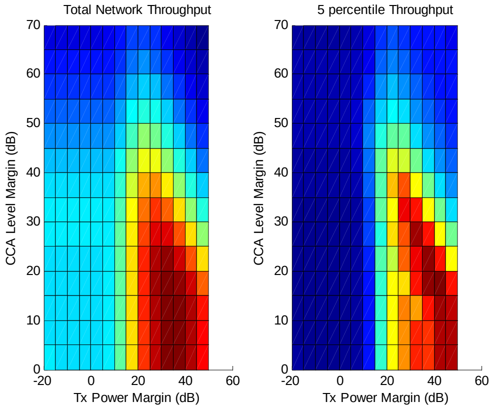

Figure 3 Dynamic CCA and TPC.

A higher CCA margin initially increases the total network throughput, but becomes detrimental beyond a certain point (roughly 25 dB margin). Same applies when the 5-percentile throughput is concerned. In short, a proper degree of CCA aggressiveness is beneficial, but overly aggressiveness may not be good at all. On the other hand, a transmit power level margin of roughly 25-30 dB is generally unchanged unless the CCA margin is overly high (see Figure 3 left hand side). In such cases, a proper transmit power margin might be more important.

V. Conclusion

We study transmit power control and clear channel assessment mechanisms for their use in licensed assisted access (LAA) networks using unlicensed spectrum. Firstly, we investigate the scheme of static clear channel assessment where all stations use the same fixed CCA value, and static transmit power control where all stations use the same fixed transmit power. Numerical results show that increasing the CCA level to a certain extent and increasing the transmit power level to a certain extent helps boost the network throughput and the 5-percentile throughput. When the latter is concerned, an interesting linear relationship exists between the optimal CCA level and the optimal TPC level. Furthermore, the optimal level of CCA and transmit power may be different, from the total network throughput point of view and from the 5-percentile user throughput point of view. Note that the optimal CCA level and optimal transmit power level are scenario dependent, e.g. on the room dimension, penetration loss, MCS table, frequency reuse among other parameters. Algorithms to automatically select CCA level and transmit power levels are thus important for practical LAA uses and will be studied in the future.

Secondly, we investigate the scheme of dynamic CCA where each STA uses its own CCA level and dynamic transmit power control where each STA uses its own transmit power, tailored to the distance (pathloss) with reference to the serving base station. A roughly 25dB CCA margin and a roughly 30 dB TPC margin generally yields an optimal network throughput, while the optimal margins for 5-percentile throughput seems more complicated. Note that with the dynamic CCA, different stations would have different CCA values, depending on the pathloss relative to the serving base station.

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