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비면허대역에서 광대역 시스템과 공존을 위한 협대역 Listen-Before-Talk 기법 연구

Narrowband Listen-Before-Talk under Coexistence with Wideband Systems in Unlicensed Spectrum

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Abstract

LTE's extension for unlicensed spectrum called Licensed Assisted Access (LAA) is equipped with Listen-Before-Talk (LBT) designed similar with the backoff mechanism of Wi-Fi for coexistence. However, Wi-Fi's backoff mechanism has not evolved from its old design for compatibility with legacy devices, thus LAA's LBT is not efficient either in utilizing spectrum. If LAA operates with no Wi-Fi systems in proximity, it can run more efficient LBT. In this paper, we propose Narrowband Clear Channel Assessment (NCCA) for narrowband transmission. In NCCA, an LAA node performs LBT in either wide or each narrow bandwidth segment. This allows multiple LAA nodes to perform simultaneous transmissions in orthogonal bandwidth segments in the same time slot. We design four variants of NCCA implementation and model their performance using a mathematical model. The coexistence performance of NCCA with conventional wideband nodes and the accuracy of the model are shown via simulation.

요 약

3GPP LTE의 비면허대역 솔루션인 Licensed Assisted Access (LAA) 기술은 Listen-Before-Talk (LBT)을 수행한다. 이는 Wi-Fi와의 공존을 위해 Wi-Fi의 백오프 기법과 매우 유사하게 설계되었다. 하지만, Wi-Fi의 백오프 기법은 기존 장치와의 호환 및 공존을 위해 오래된 설계에 기반하고 있어, LAA의 LBT 또한 스펙트럼 이용에 있어 비효율성을 보인다. 만약 근처에 Wi-Fi 시스템이 없는 환경이라면 LAA는 보다 효율적인 LBT를 수행할 수 있다. 이 논문은 협대역 전송을 위한 Narrowband Clear Channel Assessment (NCCA)를 제안한다. NCCA에서 LAA 기지국은 광대역 또는 각 협대역 밴드에서 LBT를 수행한다. 이를 통해, 복수의 LAA 노드가 서로 다른 협대역에서 동시에 전송할 수 있게 한다. NCCA 구현을 위해 네 가지의 설계안을 제시하고, 성능 예측을 위한 수학 모델을 제시한다. 기존 광대역 시스템과 공존하는 시나리오에서 시뮬레이션을 통해 NCCA의 공존 성능과 제시한 성능 모델의 정확성을 보인다.

Key words : Licensed assisted access, listen-before-talk, clear channel assessment, unlicensed spectrum, LTE

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Ⅰ. Introduction

For ever-increasing mobile traffic demands, 3rd Generation Partnership Project (3GPP) has enabled the operation of Long-Term Evolution (LTE) system in unlicensed spectrum, both in 2.4 GHz and 5 GHz, called Licensed Assisted Access (LAA) [1]. In order to support fair coexistence with other wireless systems, LAA is equipped with Listen-Before-Talk (LBT) that makes an LAA node sense the medium first and defer transmission if the medium is busy. Under the operation of LBT, LAA has been verified and proven to coexist well with Wi-Fi systems [2][3][4][5][6][7].

However, LAA's LBT was designed similarly with the backoff mechanism of Wi-Fi for coexistence. Knowing that Wi-Fi's backoff mechanism was designed several decades ago, LAA's LBT is not very efficient in utilizing spectrum. If LAA operates in a new spectrum band (e.g. 6 GHz) or in the conventional spectrum, but with no Wi-Fi systems in proximity, LAA can run more efficient LBT.

In this paper, we propose Narrowband Clear Channel Assessment (NCCA) for narrowband transmission. In NCCA, an LAA node performs LBT in either wide or each narrow bandwidth segment. This allows multiple LAA nodes to perform simultaneous transmissions in orthogonal bandwidth segments in the same time slot, while conventional LAA nodes have to wait for each's time slot to transmit if any of them is already transmitting. We design four variants of NCCA implementation and estimate their performance using a mathematical model. The coexistence performance of NCCA with conventional wideband nodes and the accuracy of the model are shown via simulation.

The rest of the paper is organized as follows. In Section II, we explain the details of NCCA. Its mathematical model is described in Section III. Section IV shows simulation results and discussion. We conclude the paper in Section V.

Ⅱ. Narrowband Clear Channel Assessment (NCCA)

NCCA is defined by that energy is measured over only a subset of the Physical Resource Block (PRB) in a carrier or in other words clear channel assessment (CCA) is only performed in a partial bandwidth that a node has been allocated for itself. Before performing a transmission, an LAA node senses medium within a specific bandwidth segment and determines if the segment is idle or busy. The segment is counted idle if no other node is currently transmitting in the same bandwidth segment. Therefore, it enables simultaneous transmissions by multiple LAA nodes in orthogonal narrowband segments, but in the same carrier.

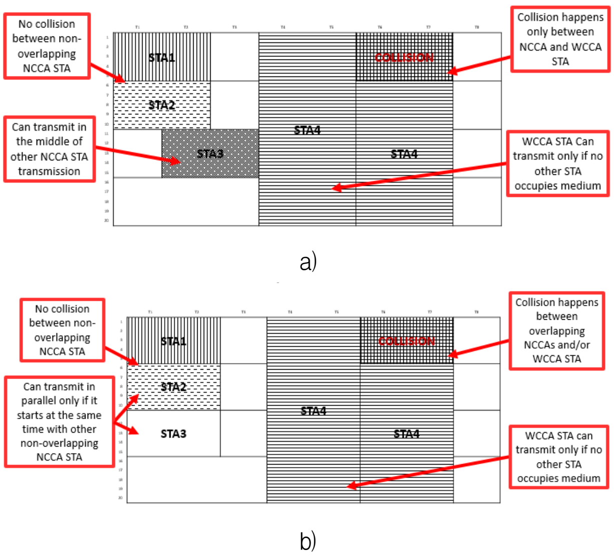

Fig. 1. Narrowband Clear Channel Assessment: a) Unsynchronized, b) Synchronized.
그림 1. 협대역 CCA: a) 비동기식, b) 동기식

The channel assessment steps of NCCA are similar with those of the conventional carrier-wide CCA, referred as wideband clear channel assessment (WCCA). Both use a backoff counter for the target medium and counts down only when the target medium is idle, and start

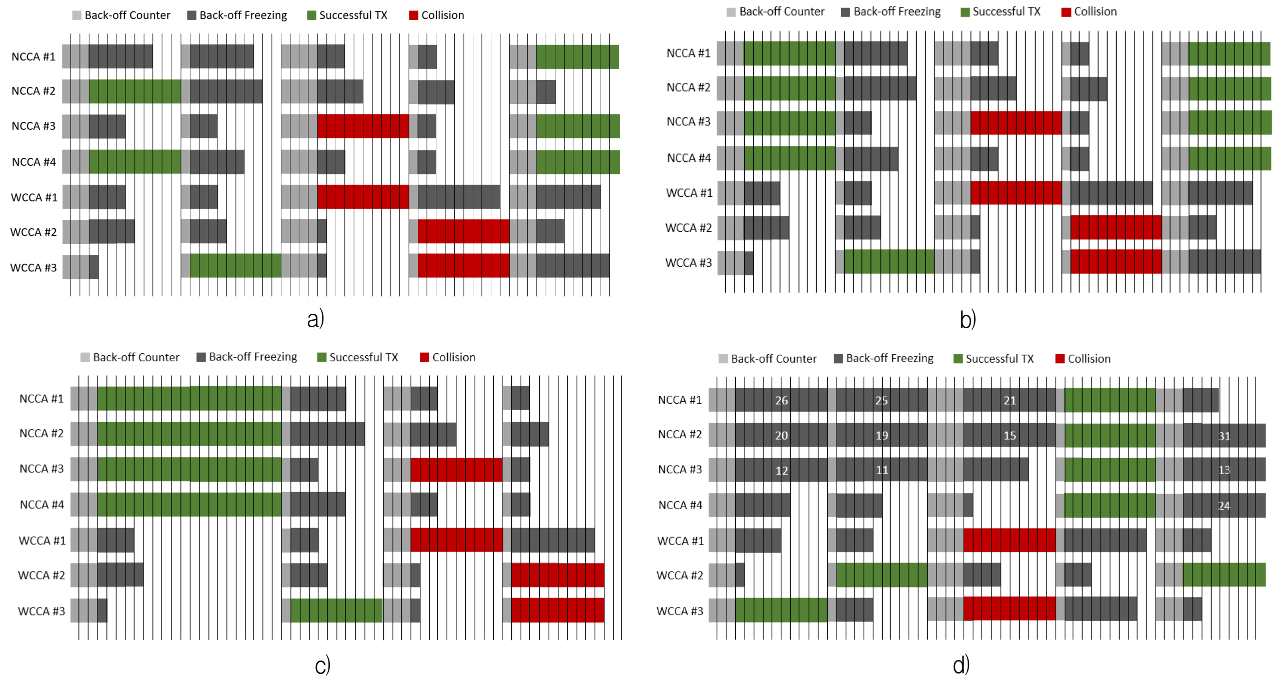

Fig. 2. NCCA implementation variants: a) NCCA with WCCA, b) NCCA with trigger signal, c) NCCA with equal data size, d) NCCA with handicapped contention window.
그림 2. NCCA 구현 방식: a) WCCA 결합, b) 트리거 시그널 사용, c) 동일 데이터 크기 사용, d) 경쟁윈도우 불이익 부여

transmission once the counter reaches zero. The difference is that WCCA senses the medium busy if there is any node transmitting whereas NCCA senses busy medium only if a transmitting node(s) is using the sensed bandwidth segment.

There could be two transmission timing cases of NCCA: (1) synchronized and (2) unsynchronized, as illustrated in Fig. 1.

In synchronized NCCA, an LAA node can start to transmit only if there is no other NCCA node currently transmitting. Simultaneous transmissions will happen if backoff counters of nodes become zero at the same time. In unsynchronized NCCA, an LAA node can transmit anytime if it senses idle medium, which means it can start to transmit while other nodes are using other bandwidth segments. We limit the focus of this paper to synchronized NCCA.

In what follows, we design four variants of NCCA implementation.

1. NCCA with WCCA (Method 1)

A node performs both NCCA and WCCA, and transmission in narrowband. Simultaneous transmissions happen only if nodes finish backoff at the same time. This method is used to maintain nodes' synchronization by letting each sense other's transmission and freeze its backoff counter. Fig. 2a shows the timing diagram.

2. NCCA with a Trigger Signal (Method 2)

Once a NCCA node is ready to transmit according to Method 1, it first transmits a trigger signal to other NBT nodes before transmitting its data to inform them of its medium reservation and the start of simultaneous transmissions. After transmission, all NBT nodes reset their backoff counters.

3. NCCA with Equal Data Size (Method 3)

The basic procedure is based on Method 2, but, instead of transmitting small data for narrowband in each transmission, a node transmits the same size of data as wideband transmission at the cost of a longer transmission duration. Fig. 2c shows the timing diagram.

4. NCCA with Handicapped Contention Window (Method 4)

The basic procedure is based on Method 2, but a NBT node has a multiplied CW to adjust coexistence behavior with other nodes in the medium. Since NCCA nodes will have increased CW, they handicap themselves for WCCA nodes so that both technologies coexist fairly in shared medium, as shown in Fig. 2d.

III. Mathematical Model

The mathematical model of the proposed method is based on the Markov Chain model of Wi-Fi presented in [8]. The description of the model (along with the simulation results of the model in Section IV) is for, but not limited to, Method 1 of Section II.1. From [8] we get the transmission and collision probabilities, respectively, as:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1)+pW(1-(2p))^m} \tag{1}$$

$$p = 1-(1-\tau)^{N-1} \tag{2}$$

where W is the minimum contention window size (CW_{min}), m is the maximum backoff stage, τ is the transmission probability, p is the collision probability, and N is the total number of contending nodes in the medium. NCCA and WCCA nodes have different transmission and collision probabilities. A WCCA node avoids collision if there is no transmission in the medium while a NCCA node avoids collision if there is no transmission of WCCA node(s) and no transmission of NCCA node(s) in the overlapping bandwidth segment. Given that M is the number of NCCA nodes (the number of WCCA nodes is given as $N-M$), the collision probabilities are given as:

$$p_{WCCA} = 1-(1-\tau_{WCCA})^{N-M-1}(1-\tau_{NCCA})^M \tag{3}$$

$$p_{NCCA} = 1-(1-\tau_{WCCA})^{N-M}(1-\tau_{NCCA})^{\max(N_0-1,0)} \tag{4}$$

where p_{WCCA} is the collision probability of a WCCA node, p_{NCCA} is the collision probability of a NCCA node, τ_{WCCA} is the transmission probability of a WCCA node, τ_{NCCA} is the transmission probability of a NCCA node, and N_0 is the average number of overlapping bandwidth between NCCA nodes and given by:

$$N_0 = \frac{M}{\left\lfloor \frac{Bandwidth_{WCCA}}{Bandwidth_{NCCA}} \right\rfloor} \tag{5}$$

where $Bandwidth_{WCCA}$ is the bandwidth of WCCA nodes, $Bandwidth_{NCCA}$ is the bandwidth segment size of NCCA nodes. The throughput of the whole system is given by:

$$TPUT = \frac{Payload \times P_s \times P_{tr}}{T_i \times (1-P_{tr}) + T_s \times P_s \times P_{tr} + T_c \times (1-P_s) \times P_{tr}} \tag{6}$$

where P_s is the probability of a successful transmission given that there is any transmission occurrence in a slot, P_{tr} is the probability that any transmission occurs in a slot, T_i is an idle slot duration, T_s is a successful transmission duration, and T_c is a collision duration. The transmission probabilities of WCCA and NCCA nodes are obtained as:

$$p_{tr} = 1-(1-\tau_{WCCA})^{N-M}(1-\tau_{NCCA})^M \tag{7}$$

$$p_{tr_{WCCA}} = 1-(1-\tau_{WCCA})^{N-M} \tag{8}$$

$$p_{tr_{NCCA}} = 1-(1-\tau_{NCCA})^M \tag{9}$$

Finally, the probability of successful transmission given that there exists a transmission attempt in a time slot is obtained in terms of the above results as:

$$P_{s_{WCCA}} = \frac{(N-M)\tau_{WCCA}(1-\tau_{WCCA})^{N-M-1}(1-\tau_{NCCA})^M}{P_{tr_{WCCA}}} \tag{10}$$

$$P_{s_{WCCA}} = \frac{M \times \tau_{NCCA}(1-\tau_{WCCA})^{N-M}(1-\tau_{NCCA})^{\max(N_0-1,0)}}{P_{tr_{NCCA}}} \tag{11}$$

Ⅳ. Simulation Results

The first simulation scenario is the coexistence of NCCA and WCCA nodes in a non-hidden environment, i.e., all nodes can sense another and are aware of other's transmissions. The total number of nodes in the environment is fixed as 20, but the combination of node types (NCCA or WCCA) is varied. The simulation is done with an increasing number of NCCA nodes starting from 0 (all use WCCA) to 20 (all use NCCA). The bandwidth used by WCCA is 20 MHz and, for NCCA, 1, 5, and 10 MHz segment cases are considered.

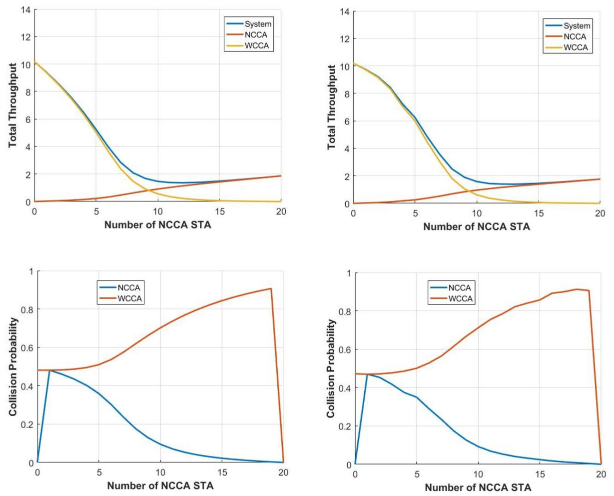

Fig. 3. Mathematical model vs. Simulation result for NBT with 1 MHz segment.
그림 3. 1 MHz 세그먼트에 대한 NBT의 수학 모델과 시뮬레이션 결과 비교

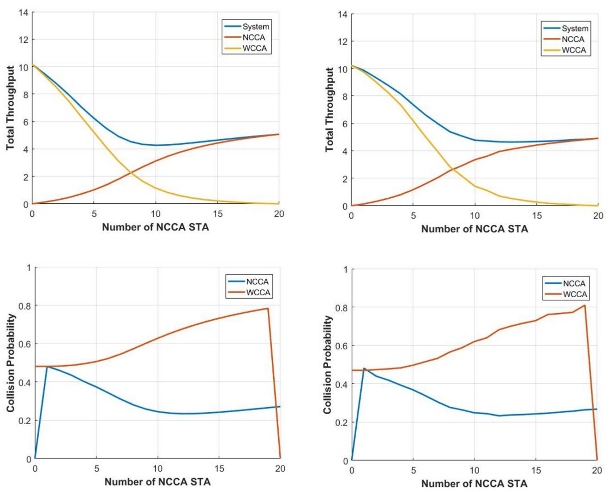

Fig. 4. Mathematical model vs. Simulation result for NBT with 5 MHz.
그림 4. 5 MHz 세그먼트에 대한 NBT의 수학 모델과 시뮬레이션 결과 비교

In Figs. 3-5, we see that the mathematical model well represents the behavior of NCCA as the model and simulation's graph resemblance is uncanny. The figures show that the model correctly estimates the throughput and collision probability with small errors.

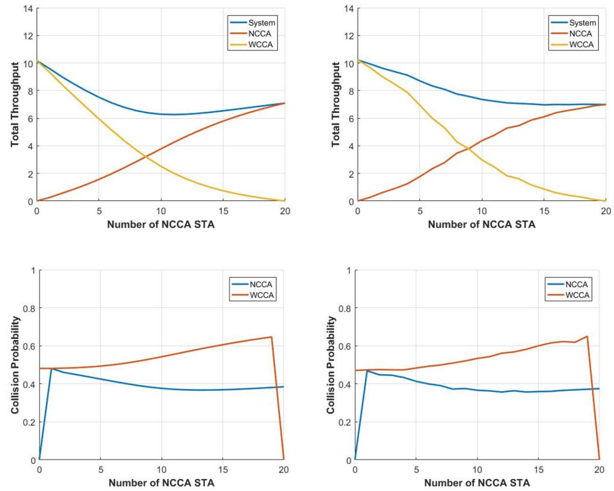

Fig. 5. Mathematical model vs. Simulation result for NBT with 10 MHz.
그림 5. 10 MHz 세그먼트에 대한 NBT의 수학 모델과 시뮬레이션 결과 비교

These figures show the result of coexistence between NCCA and WCCA nodes as well. We can see that the system throughput is decreasing as the number of NCCA nodes increases. This is because the data payload of each transmission of NCCA nodes is lower than WCCA's. We set the payload of NCCA nodes proportional to a bandwidth segment as follows:

$$Payload_{NCCA} = \left[\frac{Bandwidth_{NCCA}}{Bandwidth_{WCCA}} \right] \times Payload_{WCCA}$$

WCCA nodes experience higher collision probability than NCCA nodes. This is because WCCA nodes collide with other WCCA nodes and NCCA nodes on any bandwidth segment whereas NCCA nodes collide with WCCA nodes and the

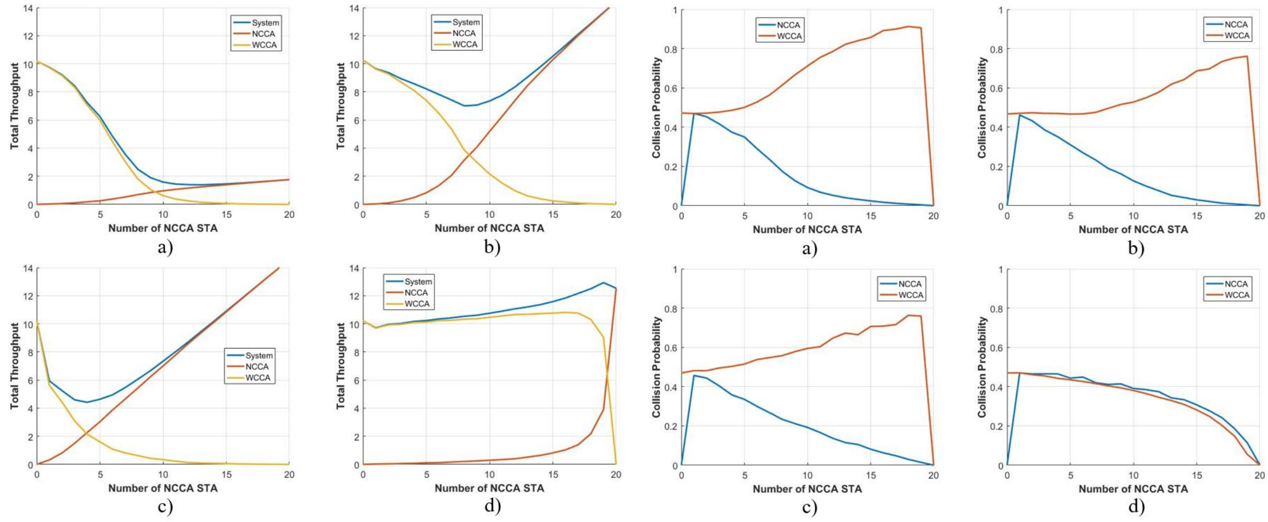

Fig. 6. Throughput and collision probability in 1 MHz segment for: a) Method 1, b) Method 2, c) Method 3, d) Method 4.
그림 6. 1 MHz 세그먼트에 대한 수율과 충돌확률 결과: a) 방법 1, b) 방법 2, c) 방법 3, d) 방법 4

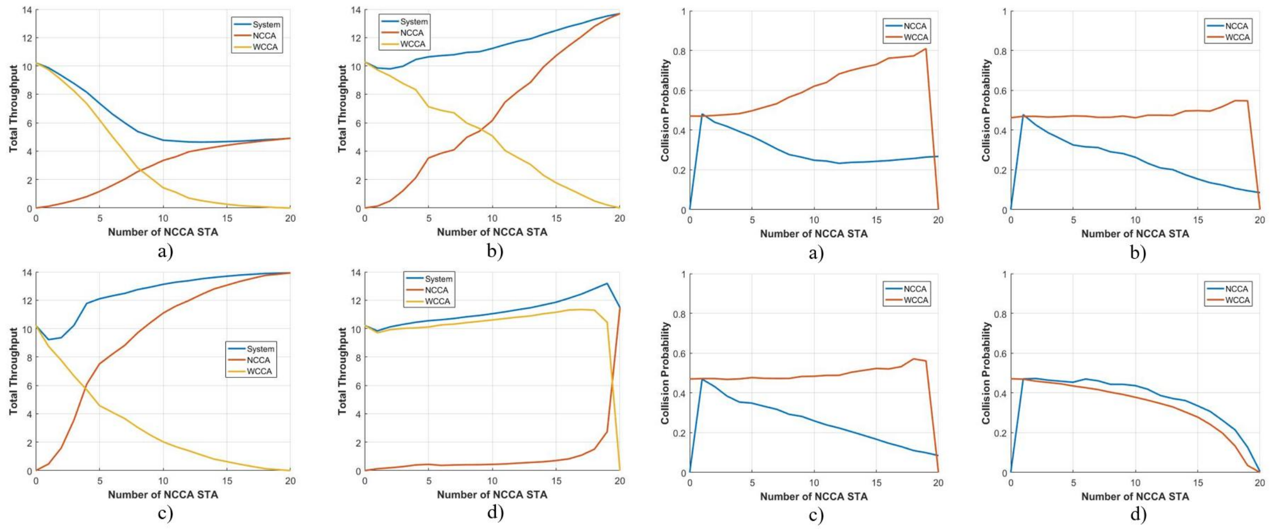

Fig. 7. Throughput and collision probability in 5 MHz segment for: a) Method 1, b) Method 2, c) Method 3, d) Method 4.
그림 7. 5 MHz 세그먼트에 대한 수율과 충돌확률 결과: a) 방법 1, b) 방법 2, c) 방법 3, d) 방법 4

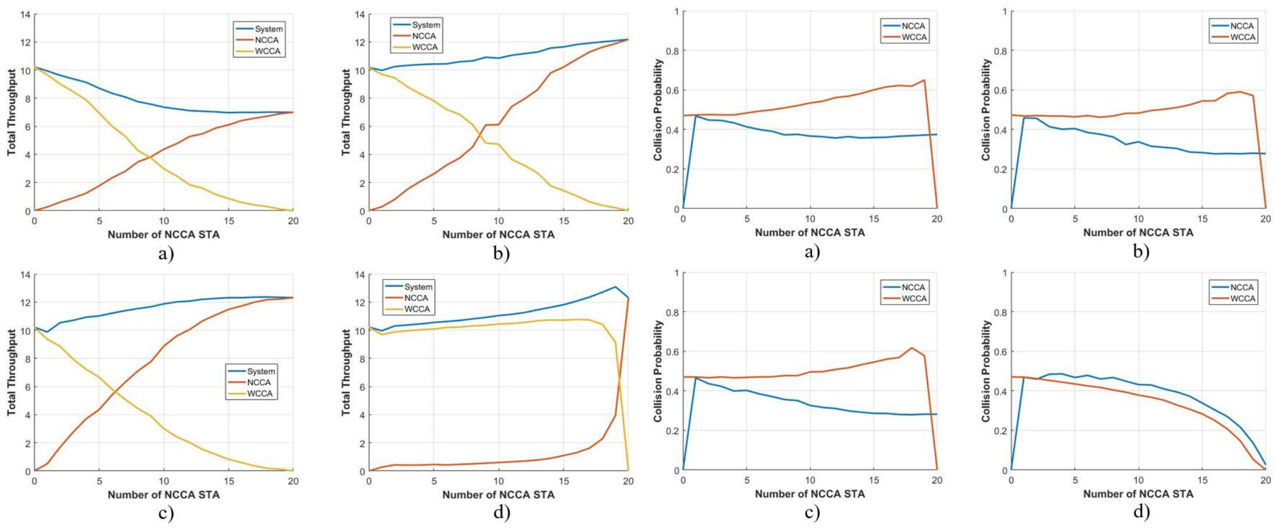

Fig. 8. Throughput and collision probability in 10 MHz segment for: a) Method 1, b) Method 2, c) Method 3, d) Method 4.
그림 8. 10 MHz 세그먼트에 대한 수율과 충돌확률 결과: a) 방법 1, b) 방법 2, c) 방법 3, d) 방법 4

NCCA nodes on the same bandwidth segment only. The throughput initially decreases because of NCCA nodes that have not kept up with decreasing WCCA nodes until the lowest point (at 10 WCCA and 10 NCCA nodes) and begins to incline as NCCA nodes contribute more to throughput.

Figs. 6-8 show comparison of different methods of NCCA implementation. The figures show that Methods 2, 3, and 4 greatly improve the system throughput compared to Method 1. In Method 2, NCCA nodes have almost no disadvantages, having any node that finishes its backoff signals the others to transmit as well. Method 2 can be interpreted as, rather than sending each payload in a narrowband, making a group of NCCA nodes send in wideband. In Method 3, the result is better than Method 1, and equal in performance to Method 2. Both Methods 2 and 3 show promising performance but WCCA nodes have higher collision probability and thus NCCA nodes occupy more time slots. In Method 4, NCCA nodes have the minimum CW of the base value multiplied by the number of nodes in the environment. From the graph, we can see that the unfiarness problem is relieved while having better throughput than Method 1, but NCCA nodes achieve significantly lower throughput than WCCA nodes.

Ⅴ. Conclusion

Narrowband Clear Channel Assessment is a method that can be considered to improve LAA performance. We designed four variants of NCCA implementation that differ in performance and coexistence. Through simulation work in coexistence scenarios with conventional wideband nodes, the varients are evaluated and compared. In the paper, we only provided simple designs and further research on detailed designs for a wider range of working environments is needed.

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