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## Abstract

Basic service set (BSS) is the fundamental building block of an IEEE 802.11 wireless local area network (WLAN). The overlapping BSS problem refers to situations that two or more systems, unrelated to each other, are in close enough proximity to hear other physically. Overlapping BSS problem may degrade the network performance severely. In this paper, a two-level carrier sensing mechanism is proposed to solve the overlapping BSS problem. In the proposed solution, a new network allocation vector is introduced to solve the overlapping BSS problem with minimal hardware requirement. Moreover, the proposed mechanism introduces very little complexity - when there is no overlapping BSS problem exists, the proposed mechanism works the same as legacy 802.11 MAC mechanism.

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*Index Terms*—WLAN, overlapping BSS problem, network allocation vector (NAV), two-level carrier sensing

## I. INTRODUCTION

A *basic service set*[5] (BSS) of IEEE 802.11 WLAN consists of a set of *stations* (STA) controlled by a single coordination function. When two or more BSSs, unrelated to each other, are close enough to hear each other physically and are operating in the same channel, the transmissions by some STAs in one BSS will affect the STAs in another BSS — this is usually called the overlapping BSS problem.

Overlapping BSS problem is very common in cellular and wireless local area networks. Figure-1 depicts a typical overlapping BSS scenario. Although current 802.11 series protocols attempt to address the overlapping BSS problem, however, from the discussion in this paper, those methods provided do not work well, therefore collisions cannot be avoided under overlapping BSS scenarios.
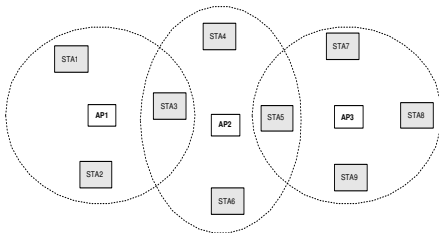


Fig. 1.  An example of overlapping BSS problem

In this paper, a novel two-level carrier sensing mechanism is proposed to solve the overlapping BSS problems. The proposed solution can achieve more efficient channel utilization by reducing the collision probability between STAs that belong to different BSSs. STAs adjust their network allocation vector (NAV) based on both legacy and two-level carrier sensing following specific rules. The proposed mechanism can maintain efficient channel usage through implicit scheduling — most collisions due to overlapping BSSs are avoided by setting appropriate deferral. Moreover, the proposed mechanism can be realized by software which makes it relatively easy to incorporate the proposed mechanism to current wireless LAN products.

The rest of this paper is organized as follows: In section-II, the background regarding the overlapping BSS problems and current solutions are reviewed. Section-III presents the proposed two-level carrier sensing mechanism for overlapping BSS problem. In Section-IV, simulation results of network throughput using both legacy 802.11 protocol and the proposed mechanism are discussed. Finally, Section-V concludes the paper.

## II. BACKGROUND

### A. IEEE 802.11

In 1997, the first IEEE 802.11 standard was published. The standard defines the *medium access control* (MAC) and *physical* (PHY) layers for a LAN with wireless connectivity. Following the first standard, several amendments, such as 802.11a, b, e are developed. According to the standards, there are two possible configurations for IEEE 802.11 WLAN — ad hoc mode (independent BSS) or infrastructure mode in which an *access point* (AP) is used to coordinate the communications between STAs.

IEEE 802.11 MAC defines two channel access mechanisms — contention based *Distributed Coordination Function* (DCF) and contention-free *Point Coordination Function* (PCF). Channel access is governed through *interframe space* such as DIFS/PIFS and SIFS — STAs can only initialize transmission after the channel is clear for DIFS/PIFS and can access channel after SIFS thereafter for the same communication exchange. In DCF, STAs compete for channel access in a distributed fashion while PCF is carried out by the *point coordinator* (PC) residing in AP.

The PC determines which STA currently get the channel access by polling the STA. Once polled, the STA can only transmit one packet and should return the channel to the AP after that. DCF and PCF can coexist by alternating the *contention period* (CP) and *contention-free period* (CFP). A CFP and a CP together are referred as a *Super-frame*.

In DCF, a STA sets its network allocation vector (NAV) according to the duration field of the received frame and defers channel access to avoid collision. When the NAV value reaches zero, the STA can contend for channel access. Moreover, physical carrier sensing is employed in DCF, which prevents channel access when the medium is not idle. In PCF, all the STAs that receive the first frame in contention free period, normally a beacon frame will set their NAVs to maxCFPDuration, and will only access channel when it is polled by the AP regardless whether there is other transmissions going on in the same channel. [1]
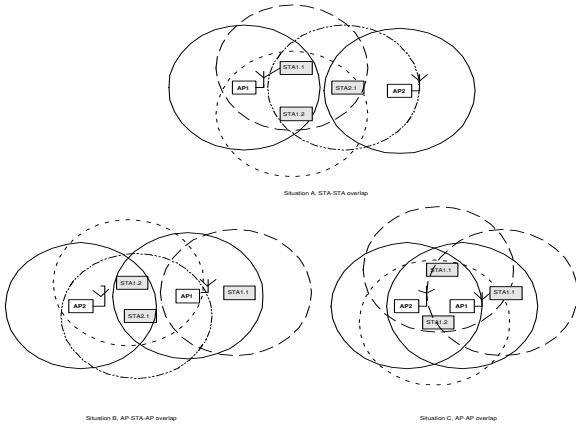
### B. Overlapping BSSs Problem



Fig. 2. Three Scenarios of Overlapping BSS Problems

Several BSSs may coexist in a WLAN, Figure-2 illustrates three scenarios of overlapping BSSs, namely, scenario A, B and C. In scenario A, the coverage area of the two BSSs are not overlapped, however, the transmission range of some STAs in one BSS (e.g. $STA_{1.1}$ and $STA_{1.2}$ in $BSS_1$) overlaps with transmission range of STAs in the other BSS (e.g. $STA_{2.1}$ in $BSS_2$), therefore, this scenario is defined as STA-STA overlap in this paper. Although this scenario is not a typical overlapping BSS case, we still call this scenario as overlapping BSS since overlapping is still exist among STAs from different BSSs. In fact, it is the most problematic situation of the three, since in this case, it is difficult for the AP and the STAs in different BSSs to obtain information of the potential interference. In [2], A mechanism using RTS/CTS is proposed in CFP to solve this problem.

Scenario B denotes the network configuration that STAs in one BSS (e.g. $STA_{1.1}$ and $STA_{1.2}$ in $BSS_1$) are able to hear transmission of AP in other BSS (e.g. $AP_2$ in $BSS_2$). In this situation, the coverage areas of the BSSs are indeed overlapped. So we define this scenario as AP-STA-AP overlap. When both BSSs are operating in CFP, there is no good solution available now.

The third scenario of overlapping BSSs — scenario C, or in other words, AP-AP overlap, shows a situation in which the APs from different BSSs can hear each other and will have the information about other BSS, hence this scenario will be relatively easy to deal with — a good scheduling algorithm [6] can be used to reduce the potential collision between STAs from different BSSs in CFP.

### C. Current Solutions for Overlapping BSSs Problem

Due to the collision and interference among STAs caused by the overlapping BSSs, channel resource are unnecessarily wasted. Hence the objective of the solution for the problem is to utilize channel efficiently. A BSS should be aware of the transmission going on in another BSS that might affect its own transmission, and should be able to manage overlapping scenarios by sharing the wireless channel fairly, preferably with a distributed mechanism.

In [5] overlapping BSS problem in CFP is considered — STAs will set their NAVs according to the CFPDurRemaining parameter in received beacon frame regardless of the origination of the beacon (self BSS or overlapping BSS). Unfortunately such mechanism doesn't help because once polled, the STA will response immediately no matter what value the NAV is. So, setting NAV will not prevent the interference and collision. Moreover, since no physical carrier sensing is performed in CFP, hence the problem of potential collision among overlapping BSSs is not addressed. In CP, there is no explicit solution for overlapping BSSs problem.

It is very desirable that overlapping BSSs can share a single channel without performance compromise. Solutions such as [2] [4] [1] have been proposed for specific scenarios and configurations. For example, [4] can only work when one BSS is in CFP and the other in CP. Solution in [1] requires different operations in CP and CFP. The scheduling scheme in [6] only works in situation C, when two APs can hear each other and makes scheduling possible. Moreover, with the demand of higher throughput (for example, IEEE 802.11n is aiming at providing throughput up to 100Mbps or higher), more efficient mechanisms such as multi-polling will be employed. However, to the best of our knowledge, there is no solution available for overlapping BSSs in multi-polling system.

In this paper, a two-level carrier sensing scheme is proposed that works for all the overlapping BSS scenarios. The proposed solution is backward compatible with legacy MAC with minimal implementation complexity. When there is no overlapping BSSs, the proposed scheme doesn't affect the legacy two-level carrier sensing at all. The detail of

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[1] see section-III-A for more detail description on NAV setting.

the two-level carrier sensing scheme is discussed in the following Section.

## III. TWO-LEVEL CARRIER SENSING FOR OVERLAPPING BSSS PROBLEM

As discussed in Section-II, overlapping BSS problem is solved by employing a two-level carrier sensing mechanism for both CP and CFP (notice that for legacy 802.11, there is no PHY sensing during CFP). In the proposed solution, STA is able to utilize channel more efficiently and reduce the waste of resource as much as possible. Carrier sensing at both PHY and MAC layer are employed: the carrier sensing at PHY layer is straightforward — a STA can transmit only when a STA detects the channel is idle for a certain period of time, thus reduce the potential collisions that may happen in legacy system. Virtual carrier sensing at MAC is employed — in addition to *network allocation vector* (NAV) in legacy 802.11, two new network allocation vectors are proposed: *self-BSS NAV* (SBNAV) and *overlapping-BSS NAV* (OBNAV). Thus, in CP, the legacy NAV then is set to be the either SBAV or OBAV, whichever is bigger. In CFP, a STA only transmits when polled and both physical carrier sensing and OBNAV indicate that channel is clear. Among those two network allocation vectors, SBNAV is in fact the legacy NAV in 802.11, while OBNAV is set to 0 when there are no overlapping BSSs and set to corresponding value when there is overlapping BSS at present.

### A. NAV Setup in legacy 802.11

In 802.11/.11e standard, STAs perform both PHY and MAC layer carrier sensing during CP. STAs set their NAV according to the duration field of RTS/CTS/DATA frames. We consider a scenario in which BSS A is overlapped by BSS B, since RTS/CTS don't have a BSS ID, RTS/CTS generated in BSS B may also reserve the channel in BSS A. On the other hand, DATA frame contains BSS ID information, STAs can theoretically use the duration information contained in DATA frame to defer channel access. However, currently most NIC manufacturers will filter out such packets without updating NAV. Such ambiguity of legacy standard leads to the uncertainty of network performance.

In CFP, no physical carrier sensing is performed in legacy standard. At the beginning of each CFP, associated STAs in the BSS set their NAV to CFPMaxDuration, and will update it according to subsequently received beacon frames, regardless of the originator of the beacon frame. NAV will be reset to 0 once STAs receive CF-End frames. STAs transmit if polled by the AP, no matter if their NAV is clear or not. Such mechanism doesn't solve the overlapping BSS problem, since in CFP, the purpose of NAV is to defer channel access for STAs that are not polled. However, for STAs being polled, there is no scheme that prevent them from interfering transmissions going on in the overlapping

BSS. Hence a more effective mechanism is needed to schedule transmission for overlapping BSSs scenario.

### B. Proposed NAV setup in Overlapping BSS

In order to differentiate the frames received from STAs (APs) that belongs to the same BSS or from overlapping BSS, and record their corresponding durations, we use two NAVs — SBNAV and OBNAV.

● Self BSS Network Allocation Vector (SBNAV)

The proposed SBNAV works in the same way as the legacy NAV. Every time a STA hears a RTS/CTS packet, it updates the SBNAV whenever necessary. (As in legacy NAV, SBNAV is only updated when the duration field of the received frame is longer than current SBNAV). Notice that since RTS/CTS frame doesn't contain information about BSS ID, the duration in those frames are always used to set SBNAV, regardless of its originator.

● Overlapping BSS Network Allocation Vector (OBNAV)

Two subtypes of OBNAV are defined, namely, the OBNAV-CP and OBNAV-CFP for the CP and CFP respectively. While the OBNAV is defined to be one of them whichever has a longer deferral time.

When there is an overlapping BSS operating in CFP, a STA that hears beacon frame from an overlapping BSS sets its OBNAV-CFP to CFPDurRemaining parameter contained in the beacon frame. If a STA is not able to receive the beacon frame, however it can receive DATA frame from the overlapping BSS, it will set OBNAV-CP according to the duration field. OBNAV-CFP may expire or be reset to 0 when the STA hears CF-End from the corresponding BSS. Besides OBNAV-CFP, a STA should also have a counter (named OB counter in this paper) to store the number of overlapping BSSs it has observed, and the OBNAV-CFP can only be reset when it has received the number of CF-Ends that equals the number of overlapping BSSs detected. Figure-3 shows an example of OBNAV setting in a multiple overlapping BSSs scenario. Notice that upon the reception of every new beacon the STA will update the OBNAV-CFP.
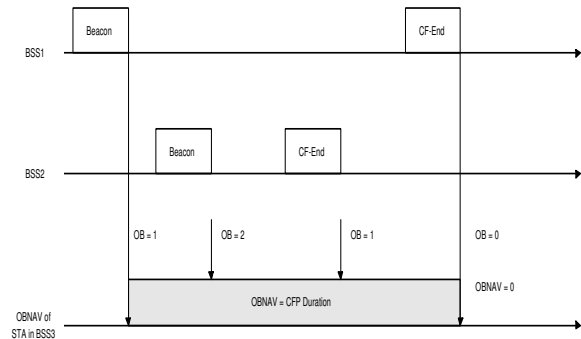


Fig. 3.  Overlapping BSS Solution—Multiple Overlapping BSSs

When the overlapping BSS is operating in CP, the RTS/CTS from overlapping BSSs are treated as SBNAV,

Since DATA frame contains BSS ID information, so STA sets and updates OBNAV-CP according to the duration field of DATA frame generated from overlapping BSSs.

• Channel Access

In the proposed overlapping BSSs solution, STAs still follow the rule of NAV — STAs won't access channel unless the NAV is zero in CP, where NAV takes the larger value of OBNAV and SBNAV. The redefinition of NAV maintains good backward compatibility. On the other hand, when polled in CFP, a STA first performs physical carrier sensing and accesses channel only when both of SBNAV and OBNAV indicate a clear channel.
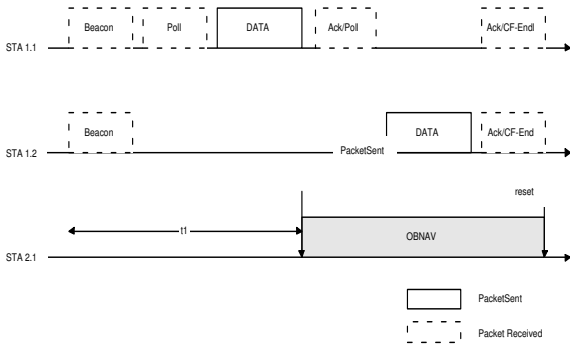


Fig. 4.  Examples—STA-STA overlap, CFP-CP

Figure-4 to Figure-9 illustrate how the proposed overlapping BSS solution works under different configuration. The three configurations discussed in section-II-B, namely—STA-STA, AP-STA-AP and AP-AP overlap are studied. In all the configurations, we define BSS1 as the primary BSS and BSS2 as the overlapping BSS. For each configuration, two scenarios are investigated. In scenario1 one BSS operates in CFP and the other operates in CP. (We always assume that BSS1 is in CFP and BSS2 in CP.[2]) In scenario 2, both BSSs operate in CFP. Scenario that both BSSs are operating in CP is the same as a large scale independent BSS and will not be discussed here.
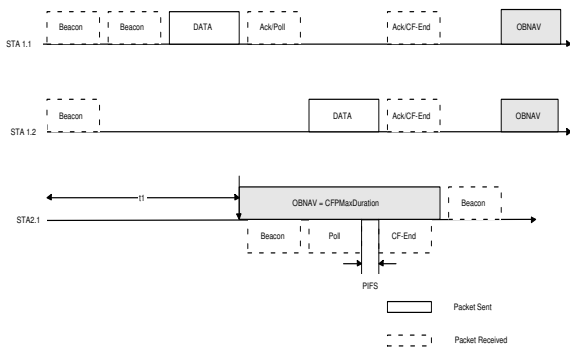


Fig. 5.  Examples—STA-STA overlap, CFP-CFP

[2]The examples presented in the paper is used to illustrate how the proposed mechanism works and will not cover every possible scenario of overlapping BSS

Figure-4 depicts an example of STA-STA overlap, CFP-CP scenario. In this scenario, since $STA_{2.1}$ cannot hear the beacon from $AP_1$, it will not be able to set OBNAV-CFP. Therefore it is not guaranteed that $STA_{2.1}$ will not interfere with communications in $BSS_1$. On the other hand, $STA_{2.1}$ is able to hear transmissions from $STA_{1.1}$ and $STA_{1.2}$, it can set its OBNAV-CFP according to the DATA frame transmitted by $STA_{1.1}$ and $STA_{1.2}$ and won't interfere with those transmissions. On the other hand, if $STA_{2.1}$ transmits ahead of $STA_{1.1}$, $STA_{1.1}$ and $STA_{1.2}$ are able to set their own OBNAV-CP according to $STA_{2.1}$ and don't response to the polling. Or, $AP_1$'s polling may collide with $STA_{2.1}$'s transmission. In both cases, (not shown in Figure-4), $STA_{1.1}$ and $STA_{1.2}$ will not transmit, therefore collisions are avoided, and $AP_1$ will terminate CFP using CF-End frame when both polls timeout. However, if there is a $STA_{1.3}$ that resides outside the transmission range of $STA_{2.1}$, its communication with $AP_1$ is not affected. Simultaneous communications in $BSS_1$ and $BSS_2$ are made possible through this mechanism.

Figure-5 depicts an example of STA-STA overlap, where both BSSs operate in CFP. $AP_1$ starts CFP first by sending out beacon and polling, and $STA_{2.1}$ will set its OBNAV-CFP. When $AP_2$ transmits beacon and polling frames, since $STA_{2.1}$ resides in both $STA_{1.1}$ and $STA_{1.2}$'s transmission range, these frames might collide with DATA frame from $STA_{1.2}$, therefore $STA_{2.1}$ doesn't respond and $AP_2$ detects the timeout and terminates CFP by CF-End. When $AP_2$ transmits beacon and polling the second time, $STA_{1.1}$ and $STA_{1.2}$ set their OBNAV-CFPs when $STA_{2.1}$ transmits DATA frame. By this means, the potential collisions between STAs from different BSSs are avoided, and the channel is shared between two BSSs efficiently.
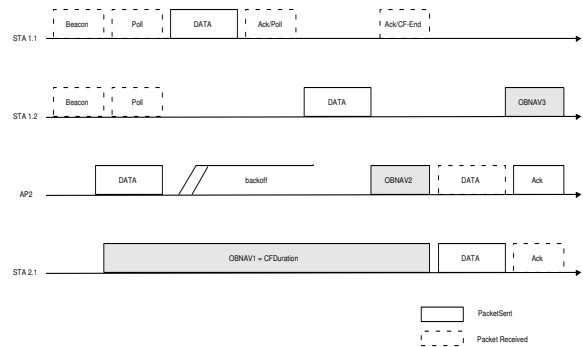


Fig. 6.  Examples—AP-STA-AP overlap, CFP-CP

Figure-6 depicts an example of AP-STA-AP overlap, CFP-CP scenario. At the beginning of $BSS_1$'s CFP, $AP_1$ transmits beacon frame; $STA_{2.1}$ sets OBNAV-CFP according to the CFPDurRemaining parameter in beacon frame. During this period, $STA_{2.1}$ will not compete for the channel. Even if $AP_2$ sends DATA, $STA_{2.1}$ will not acknowledge. Thus the collisions with transmissions in $BSS_1$ are avoided. On the other hand, since $AP_2$ cannot hear $AP_1$ but can hear $STA_{1.1}$, so $AP_2$ will set OBNAV-

CFP when receives DATA frame sent by $STA_{1.1}$. When CFP in $BSS_1$ is complete, $AP_1$ sends out CF-End, $STA_{2.1}$ and $AP_2$ resets OBNAV-CFP to 0, then $AP_2$ and $STA_{2.1}$ can exchange packets.
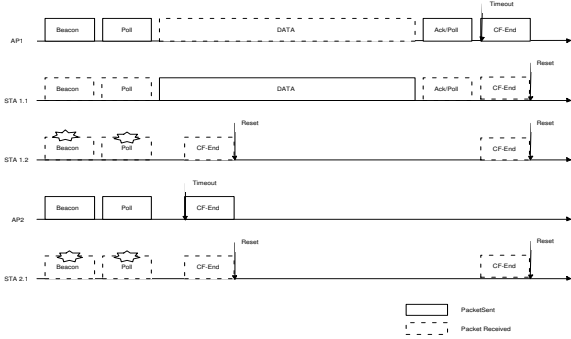


Fig. 7.  Examples—AP-STA-AP overlap, CFP-CFP

Figure-7 depicts an example of AP-STA-AP overlap, CFP-CP scenario. At very beginning, both APs transmit beacon and polling frames, Since APs can not hear each other, the beacon (and polling) frames will collide at $STA_{1.2}$ and $STA_{2.1}$. However, $STA_{1.1}$ can receive polling correctly and begin to response, $STA_{1.2}$ and $STA_{2.1}$ will not response to the polling. Thus first $AP_2$ terminates CFP with CF-End followed by $AP_1$. Upon receiving CF-Ends, STAs will wait until OB counter reaches 0 before they reset the OBNAV-CFP. This accounts for the multiple overlapping BSS situation. In this example, $STA_{1.2}$ and $STA_{2.1}$ receive multiple CF-Ends but the corresponding beacon frames collide, hence their OB counters are always 0 and OBNAV-CFP can be reset. When $AP_2$ starts another CFP (not shown in the Figure), both $STA_{1.2}$ and $STA_{2.1}$ receive the beacon $STA_{1.2}$ will set its OBNAV-CFP accordingly and increase its OB counter and $STA_{2.1}$ will response. When $STA_{2.1}$ sends DATA to $AP_2$, $AP_1$ can overhear the DATA frame and set OBNAV-CFP. $STA_{1.2}$ resets the OBNAV-CFP when it hears the CF-End/ACK frame from $AP_2$.
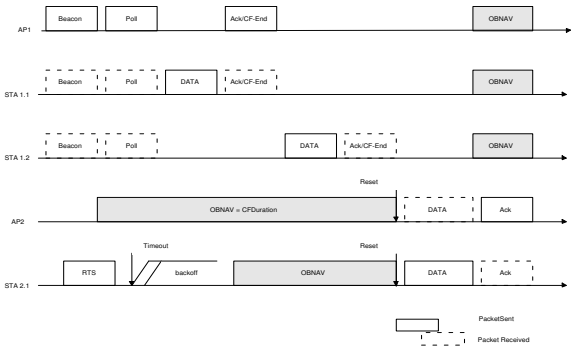


Fig. 8.  Examples—AP-AP overlap, CFP-CP

Figure-8 and Figure-9 depict two examples of AP-AP overlap, CFP-CP and CFP-CFP respectively. In this case, $AP_2$, $STA_{1.2}$ and $STA_{1.1}$ can hear all STAs and APs in
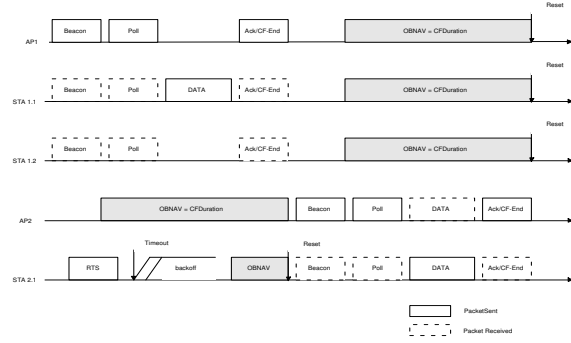


Fig. 9.  Examples—AP-AP overlap, CFP-CFP

the network, while $AP_1$ can hear all STAs and APs except $STA_{2.1}$ and vice versa. For CFP-CP, $AP_2$ and $STA_{2.1}$ have to wait DIFS to access channel, while $AP_1$ only need to wait PIFS. When $AP_2$ hears the beacon from $AP_1$, it will set its OBNAV-CFP. Although $STA_{2.1}$ can not hear beacon from $AP_1$, it can hear the DATA frames sent by both $STA_{1.1}$ and $STA_{1.2}$, hence it is able to set OBNAV-CFP too. Upon receiving the CF-End/ACK frame from $AP_1$, $AP_2$ and $STA_{2.1}$ will reset OBNAV-CFP. When $AP_2$ accesses the channel, all STAs (AP) from $BSS_1$ can hear the DATA frame and set OBNAV-CP accordingly.

For CFP-CFP, given that APs can hear each other, when $AP_1$ transmits beacon, $AP_2$ sets OBNAV-CFP. In the same way as CFP-CP scenario, $STA_{2.1}$ sets OBNAV-CFP upon reception of DATA frames from $STA_{1.1}$ and $STA_{1.2}$. When $AP_2$ transmits beacon frame, all STAs and $AP_1$ set OBNAV-CFP and OBNAV-CFP are reset upon reception of CF-End/ACK frame.

## IV. PERFORMANCE ANALYSIS

In this section, the performance of legacy IEEE802.11 standard and proposed overlapping BSS solution are obtained through *opnet* simulation. All three configuration discussed in Section-II are studied, for each configuration, both CFP-CP and CFP-CFP scenarios are simulated. In DCF, each STA chooses destination from STAs in the same BSS with same probability. The traffic load parameters of each STA are set to be same with inter-arrival time varies from 6e-3 s to 1e-3s. The traffic load and WLAN parameters used in the simulations are summarized in Table-I. In Table-I, on time/off time and CFP beacon multiple are *opnet* parameters — the on/off time indicate the the length that the packet generation module in *opnet*, and each beacon interval contains both CFP and CP period, CFP period is 5 second long and CP period is 5 second long too.

Each scenario is run for 100 second and repeated 10 times. Both individual and overall network throughput is measured.

As expected, when both BSSs are operating in CP, the overlapping BSSs work as an large IBSS, simulation

| Traffic Parameter | Value | WLAN Parameter | Value |
|---|---|---|---|
| packet size | 1024 bytes | CFP beacon multiple | 1 |
| On time | 100s | beacon interval | 10s |
| Off time | 2s | CFP period | 5s |
| channel bandwidth | 11Mbps | | |

TABLE I

TRAFFIC AND WLAN PARAMETERS USED IN SIMUALTION

validates this analysis.[3]

CFP-CP and CFP-CFP overlapping scenarios are more interesting to study. Due to the space limitation, only the simulation result of CFP-CFP overlapping is presented here. More detail simulation results can be found in [3].

Figure-10 to Figure-12 illustrate the simulation result of STA-STA, AP-STA-AP and AP-AP overlapping, CFP-CFP scenario respectively. Throughput of individual node as well as overall BSS are plotted as inter-arrival time varies from 6e-3 s to 1e-3s.
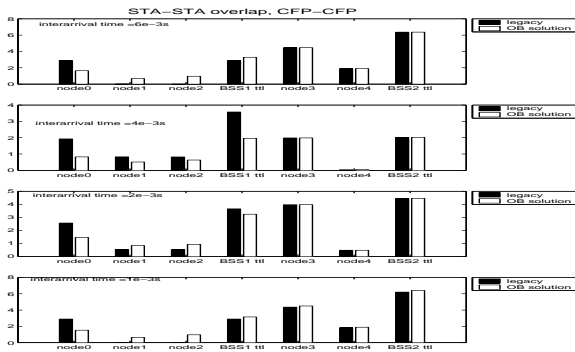


Fig. 10.  Simulation Results, STA-STA overlap, CFP-CFP
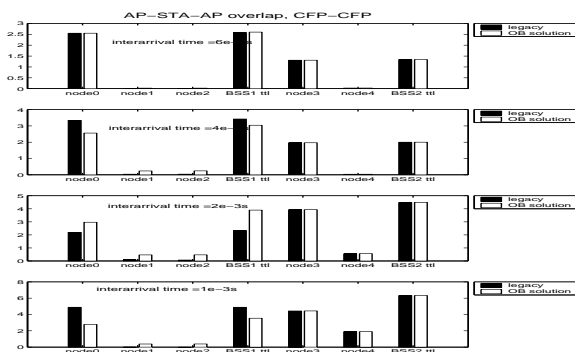


Fig. 11.  Simulation Results, AP-STA-AP overlap, CFP-CFP

From above figures we can observe that with legacy IEEE 802.11 standard, for both BSSs, there exist serious throughput imbalance among AP and STAs (in the extreme case, the throughput at specific node is 0). The usage of two level carrier sensing mechanism helps to remedy such imbalance. The overall network throughput for each BSS is maintained as the same level. Notice we tried to simulate

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[3]Due the limited space, related simulation results are not shown here.

the worst case scenario by creating large amount of collision — the simulation is configured so that both APs start CFP at exactly 1 second.
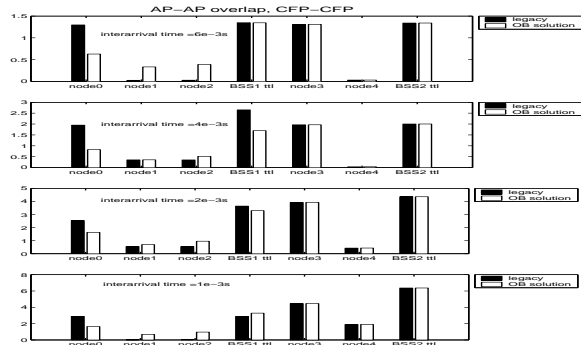


Fig. 12.  Simulation Results, AP-AP overlap, CFP-CFP

The proposed two level carrier sensing mechanism has demonstrated its advantage in adaptive channel access reservation and scheduling. In the future, the authors will work on the enhancement of this scheme to overcome the potential over-reserve problem, that is, simultaneous transmission will set up OBNAV at both BSSs thus the channel is wasted due to unnecessary deferral at both BSSs.

## V. CONCLUSION

In this paper, overlapping BSS problem was studied and analyzed. The cause of such problem and its effect on performance were illustrated. A novel two-level carrier sensing mechanism for solving overlapping BSS problem is proposed by introducing a new NAV to account for interference from overlapping BSSs. Simulation results show that the proposed mechanism can reduce the collision probability and improve the overall network performance when overlapping BSS is present. On the other hand, the proposed mechanism does not affect network performance of single non-overlapped BSS, Moreover, the proposed mechanism can be realized all by software thus impose little implementation complexity.

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