Broadcast Collision and Overhead Tradeoff for Enhanced Broadcast Service in IEEE 802.11bc

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***Abstract*—IEEE 802.11bc introduces enhanced broadcast service (EBCS) to improve data broadcast scheduling and authentication performance in wireless local network (WLAN). The essential design in the EBCS is introducing a central scheduling scheme for data broadcasting, and this makes that the conventional distributed coordination function (DCF) based broadcast performance analysis does not apply. Thus, in this paper, we investigate the frame collision between DCF-based unicast data and scheduling-based broadcast data within the framework of IEEE 802.11bc, which has not been explored yet. Specifically, we study the tradeoff among station arrival intensity, broadcast and unicast frame collision, and broadcast control frame transmission interval, which directly determines the broadcast overhead. We derive an analytical model to quantify the above performance tradeoff. Based on the analytical model and simulation test, we optimize the broadcast control frame transmission interval to balance the broadcast overhead and data collision.**

***Index Terms*—IEEE 802.11bc, enhanced broadcast service, central scheduling, collision probability**

I. Introduction

To satisfy the increasing broadcast demand over wireless local area network (WLAN), such as the stadium and virtual reality (VR) eSports video distribution, IEEE 802.11bc was designed to provide enhanced broadcast service (EBCS) in the WLAN. Specifically, to improve the downlink (DL) broadcast scheduling, IEEE 802.11bc introduces a central scheduling broadcast mechanism [1], which adopts the EBCS Info frame to centrally control the downlink broadcast frame scheduling. In this updated data broadcast scheduling scheme, the EBCS Info frame and the broadcasting data frame are periodically scheduled, which is completely different to the conventional distributed coordination function (DCF) mechanism.

Besides the broadcast service, the WLAN has to provide unicast service. The data delivery performance in the presence of both broadcast and unicast data has to be fully explored to provide a fair evaluation for data broadcast in the IEEE 802.11bc. Regarding this, the current literature mainly focuses on the joint broadcast and unicast performance analysis within the DCF framework. Specifically, Wang *et al*. [2] and Oliveira *et al*. [3]–[5] explore the extended two-dimensional Markov model to evaluate the transmission success probability, throughput and delay, Wang *et al*. [6] and Peng *et al*. [7], [8] focus on reducing broadcast collision to improve broadcast efficiency, Kim *et al*. [9] analyzes the broadcast packet loss performance in a multi-access point (AP) broadcasting system, and Xie *et al*. [10], Ma *et al*. [11], Sheu *et al*. [12] and Tang *et al*. [13] concentrate on improving the broadcast reliability.

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However, since the above literatures focus on the broadcast performance analysis within the DCF framework, they cannot be directly applied to the EBCS performance analysis in the IEEE 802.11bc network, which adopts a completely updated central scheduling data broadcast scheme. To be specific, for the EBCS in the IEEE 802.11bc, since the broadcast data scheduling time is periodically announced by the EBCS Info frame, if the station (STA) does not receive the EBCS Info frame, it cannot obtain the broadcast data frame scheduling information. Then, if the STA initiates an uplink unicast transmission in the broadcast period, the frame collision between DCF-based unicast data and scheduling-based broadcast data would happen.

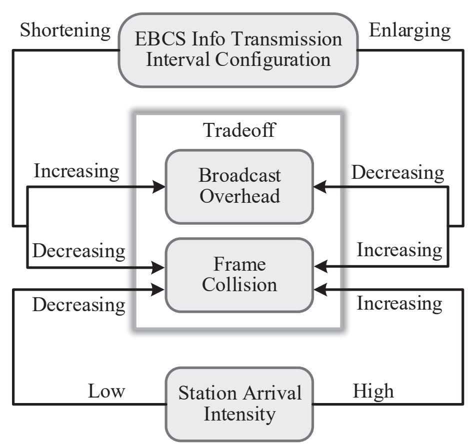

Fig. 1. Tradeoff Among EBCS Info Frame Transmission Interval, STA Arrival Intensity, and Frame Collision

As in Fig. 1, to timely update the broadcast data scheduling period, the EBCS Info frame transmission interval should be shorten, and this can make that the new joining STA can obtain the EBCS data scheduling period with a short delay, which will reduce the frame collision between scheduling-based broadcast data and DCF-based unicast data. However, shortening the EBCS Info frame transmission interval would lead to that more EBCS Info frames have to be transmitted, and this would increase the network broadcast overhead. On the contrary, enlarging the EBCS Info frame transmission interval can reduce the network broadcast overhead, but the broadcast and unicast data frame collision probability can be increased. Thus, the tradeoff among EBCS Info frame transmission interval, station arrival intensity, broadcast and unicast frame collision should be deliberately considered.

Motivated by above, in this paper, we focus on the tradeoff among station arrival intensity, broadcast and unicast frame collision, and EBCS Info frame transmission interval, which has not been explored yet. Our main contributions are as follows:

- We specifically investigate the tradeoff among the EBCS Info frame transmission interval, station arrival intensity, broadcast overhead and frame collision for the IEEE 802.11bc;
- We derive an analytical model for the collision probability between scheduling-based DL EBCS data frame and DCF-based unicast data frame within the framework of IEEE 802.11bc. Based on this model and simulation test, we provide an optimized broadcast parameter configuration to balance the broadcast overhead and frame collision for the IEEE 802.11bc network.

The rest of this paper is organized as follows. We describe the DL EBCS broadcast procedure in Section II, and analyze the broadcast and unicast frame collision probability and the broadcast overhead in Section III. We show the simulation results in Section IV, and summarize this paper in Section V.

II. DL EBCS in the IEEE 802.11bc Network

To enhance broadcast performance in the WLAN, IEEE 802.11bc introduces EBCS Info frame to announce the scheduling period for the broadcast data frame [14]. As in Fig. 2, the EBCS AP shall periodically broadcast EBCS Info frames at an interval T_I. The EBCS Info frame contains the scheduling period information of EBCS data frame. After receiving the EBCS Info frame, the STA can obtain the broadcast data in the specified time period. We denote T_D as EBCS data frame transmission interval and N as the number of EBCS data frame within T_I. We write the time duration of each EBCS data frame as T_E, and assume T_E is fixed for each EBCS data frame.

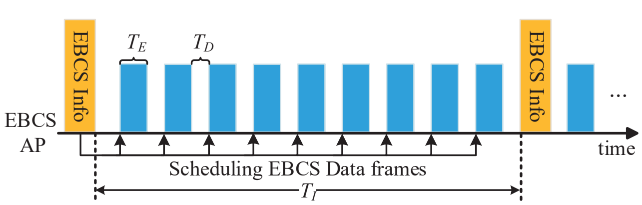

Fig. 2. EBCS Scheduling in the IEEE 802.11bc

III. DL EBCS Frame and UL Unicast Frame Collision Versus Broadcast Overhead

In this section, we analyze the collision performance between scheduling-based DL EBCS data frame and DCF-based unicast data frame for the IEEE 802.11bc network. Since the EBCS Info frame transmission interval directly determines the broadcast overhead, we evaluate the broadcast overhead as transmission frequency of the EBCS Info frame.

For the frame collision analysis, we assume that the newly arrived STA joins the network after AP broadcasts the EBCS Info frame. Since missing the EBCS Info frame, the STA cannot obtain the DL EBCS data frame scheduling period, and if it initiates an uplink (UL) transmission at the specified DL broadcast period, the UL unicast frame may collide with the DL EBCS data frame. In addition, since the STA can obtain the coming-up EBCS Info frame after it joins the network, we only focus on the unicast and broadcast frame collision probability over one EBCS Info frame transmission interval.

Since each EBCS Info frame transmission interval T_I consists of $(N+1)$ EBCS data frame transmission interval T_D, we first analyze the frame collision probability Z_i within i-th T_D.

To facilitate the paper, the main parameters used in our model are as follows:

T_I	EBCS Info frame transmission interval;
T_D	EBCS data frame transmission interval;
N	number of EBCS data frame within T_I;
T_E	time duration of EBCS data frame;
T_B	random backoff time;
T_F	duration of a DIFS in IEEE 802.11;
K	the arrival STA number within T_D;
t_j	the arrival time of the j-th STA within T_D;
U_j	time duration of j-th UL unicast data frame;
$P(\mathrm{C}\mid K=\xi)$	the collision probability within T_D for the given the arrival STA number ξ;
$P(K=\xi)$	the probability that the arrival STA number is ξ within T_D;
Z_i	the collision probability in the i-th T_D;
Q	the total collision probability within T_I;
λ	average STA arrival intensity;
$f(t_\xi)$	the probability distribution function of t_ξ;
$a(x)$	the probability distribution function of U_ξ;
$1/\mu$	average time duration of UL unicast data frame;

A. Frame Collision Probability Within T_D

As shown in Fig. 3, we assume that K STAs access the network in the i-th T_D and each STA has an UL unicast traffic to send. For the UL unicast transmission, the STA adopts the DCF scheme. The STA has to monitor the channel until an idle period, which equals to a distributed interframe space (DIFS), is detected. Then, the STA shall generate a random

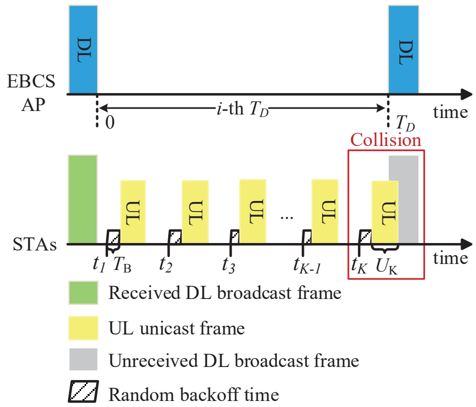

Fig. 3. Frame Collision between DL Broadcast Data Frame and UL Unicast Data Frame Within T_D

backoff time before transmitting. When the STA's backoff time T_B decreases to zero, the STA initiates an UL unicast transmission. For STA j, we write its arrival time as t_j and its UL unicast data transmission duration as U_j.

We assume that K STAs arrive sequentially within T_D, where the last unicast transmission STA is indexed as K and the UL unicast frame of K-th STA collides with the DL EBCS data frame. Since the transmission end time of the k-th STA, $k = 1, 2, \cdots, K-1$, is before the transmission start time of the K-th STA. Thus, the previous $(K-1)$ STAs cannot collide with the DL EBCS data frame. Therefore, we only analyze the collision between the DL EBCS data frame and the UL unicast data frame of the K-th STA.

From Fig. 3, we can observe that for the i-th EBCS data frame transmission interval, the transmission start time of DL EBCS data frame is T_D. Thus, for the K-th STA, the frame collision happens only if

$$t_K + T_F + T_B + U_K > T_D, \tag{1}$$

where T_F is the duration of a DIFS in IEEE 802.11.

For the i-th T_D, given the arrival STA number ξ, the frame collision probability, $P(\mathrm{C}|K=\xi)$, can be formulated as

$$\begin{aligned} &P(\mathrm{C}|K=\xi) \qquad (2)\\ =&P(t_\xi + T_F + T_B + U_\xi > T_D | 0 \le t_\xi + T_F + T_B \le \\ &T_D, K=\xi) \cdot P(0 \le t_\xi + T_F + T_B \le T_D | K=\xi). \end{aligned}$$

The right of (2) is determined by the probability distribution of t_ξ and U_ξ, which are described in the subsection B and subsection C.

We denote the frame collision probability in the i-th T_D as Z_i. Then, given the probability distribution of the arrival STA number $P(K=\xi)$, Z_i can be written as

$$Z_i = \sum_{\xi=1}^{M} P(\mathrm{C}|K=\xi) P(K=\xi), \tag{3}$$

where M is the maximum arrival STA number within T_D.

B. Uplink Unicast Frame Arrival Model

Given (3), to analyze the STA arrival distribution $P(K=\xi)$ and to derive the probability distribution of t_ξ and U_ξ, we assume that the STA arrival process follows a Poisson process, and the average STA arrival intensity is λ. In addition, We suppose that the arrival time are independent among STAs [15]. For the Poisson process with STA arrival intensity λ, we have

$$P(K=\xi) = \frac{(\lambda T_D)^\xi e^{-\lambda T_D}}{\xi!}. \tag{4}$$

Then, we suppose that the arrival time t_ξ $(\xi = 1, 2, \ldots)$ are independent and identically distribution (i.i.d) with the probability distribution function (pdf) $f(t_\xi)$. According to the Poisson distribution, we have

$$f(t_\xi) = \frac{\lambda^\xi}{\Gamma(\xi)} (t_\xi)^{\xi-1} \cdot e^{-\lambda t_\xi}, \tag{5}$$

where $\Gamma(\xi)$ is the gamma function.

In addition, for the UL unicast transmission, we assume that the random backoff time T_B is uniformly distributed [16] between 0 and $w-1$, i.e., $T_B = U(0, w-1) \times \sigma$, where $U(0,x)$ is the uniform distribution function between 0 and x, w is the current contention window (CW) size, and σ is one backoff slot. When T_B decreases to zero, the STA transmits its UL unicast data frame.

Moreover, we suppose that the UL unicast data frame transmission duration, U_ξ, is exponentially distributed [17]. We denote the pdf of U_ξ as $a(x)$, and the transmission duration follows the exponential distribution with mean $1/\mu$, i.e.,

$$a(x) = \mu e^{-\mu x}, x \ge 0. \tag{6}$$

C. Collision Probability Within T_D Given the Arriving STA Number

To derive $P(\mathrm{C}|K=\xi)$ in (2), according to the probability distribution of t_ξ in (5) and U_ξ in (6), we have

$$\begin{aligned} &P(\mathrm{C}|K=\xi) \qquad (7)\\ =&P(U_\xi > T_D - T_B - T_F - t_\xi | 0 \le t_\xi \le T_D - T_B - T_F, \\ &K=\xi) \cdot P(0 \le t_\xi \le T_D - T_B - T_F | K=\xi) \\ =&\int_0^{T_D - T_B - T_F} f(t_\xi) \cdot \left[\int_{T_D - T_B - T_F - t_\xi}^{\infty} a(U_\xi) dU_\xi \right] dt_\xi \\ =&\int_0^{T_D - T_B - T_F} \left[\frac{\lambda^\xi}{\Gamma(\xi)} (t_\xi)^{\xi-1} \cdot e^{-\lambda t_\xi} \cdot e^{-\mu(T_D - T_B - T_F - t_\xi)} \right] dt_\xi. \end{aligned}$$

D. Frame Collision Probability Within T_I

Using (4) and (7), the equation (3) can be formulated as

$$\begin{aligned} Z_i = &\sum_{\xi=1}^{M} \frac{(\lambda T_D)^\xi e^{-\lambda T_D}}{\xi!} \times \qquad (8)\\ &\int_0^{T_D - T_B - T_F} \left[\frac{\lambda^\xi}{\Gamma(\xi)} (t_\xi)^{\xi-1} \cdot e^{-\lambda t_\xi} \cdot e^{-\mu(T_D - T_B - T_F - t_\xi)} \right] dt_\xi. \end{aligned}$$

Since each EBCS Info frame transmission interval T_I consists of $(N+1)$ EBCS data frame transmission interval T_D, given the frame collision within T_D as in (8), we write the total collision probability in T_I as Q. Then, we have

$$Q = \sum_{i=0}^{N} Z_i \tag{9}$$

$$= (N+1)\sum_{\xi=1}^{M} \frac{(\lambda T_D)^{\xi} \exp^{-\lambda T_D}}{\xi!} \times$$

$$\int_{0}^{T_D - T_B - T_F} \left[\frac{\lambda^{\xi}}{\Gamma(\xi)} (t_{\xi})^{\xi-1} \cdot e^{-\lambda t_{\xi}} \cdot e^{-\mu(T_D - T_B - T_F - t_{\xi})} \right] dt_{\xi}.$$

IV. Simulation Results and Performance Evaluation

In this section, we evaluate the tradeoff between DL broadcast frame collision probability and broadcast overhead for the IEEE 802.11bc network. We study the frame collision probability regarding EBCS Info frame transmission interval T_I, STA arrival intensity λ, the average UL unicast transmission duration $1/\mu$, and the number of DL broadcast data frame N. Given the simulation results, we give the optimized broadcast parameters configuration to provide an improved tradeoff between broadcast frame collision and the broadcast overhead.

A. Simulation Setup

We validate the frame collision probability by considering a periodic DL data broadcast scenario, as shown in Fig. 2. We specify the beacon interval as 100ms, the backoff slot as 20μs, the initial contention window as 15, the duration of a DIFS T_F as 34μs, the time duration of the EBCS data frame T_E as 10ms, and the EBCS Info frame transmission interval T_I as 300ms$\sim$2000ms. These parameters follow the specification in [11] and are summarized in Tab. I.

Moreover, the EBCS Info frame transmission interval T_I and the EBCS data frame transmission interval T_D has to satisfy the constraint $T_I > N(T_D + T_E)$. To reduce broadcast overhead, we minimize T_I, and set $T_I = N(T_D + T_E) + T_D$.

TABLE I
PARAMETERS CONFIGURATION IN IEEE 802.11BC

Parameter	value
Beacon interval	100ms
Backoff slot, σ	20μs
Initial Contention window, W_0	15
Duration of a DIFS in IEEE 802.11, T_F	34μs
Maximum arrival STA number within T_D, M	20
Time duration of EBCS data frame, T_E	10ms
EBCS Info frame transmission interval, T_I	300 $\sim$ 2000ms

B. Collision Performance Analysis

We first investigate the frame collision probability versus T_I and λ, by setting $N = 10$, $1/\mu = 5$ms. From Fig. 4, we can observe that the collision probability increases as λ grows. In addition, there is a peak for the collision probability as T_I increases. Specifically, when $\lambda = 5$, the collision probability increases as T_I increases. However, when $T_I \geq 1700$ms, T_I has a marginal impact on the frame collision probability, and the frame collision probability is mainly determined by λ.

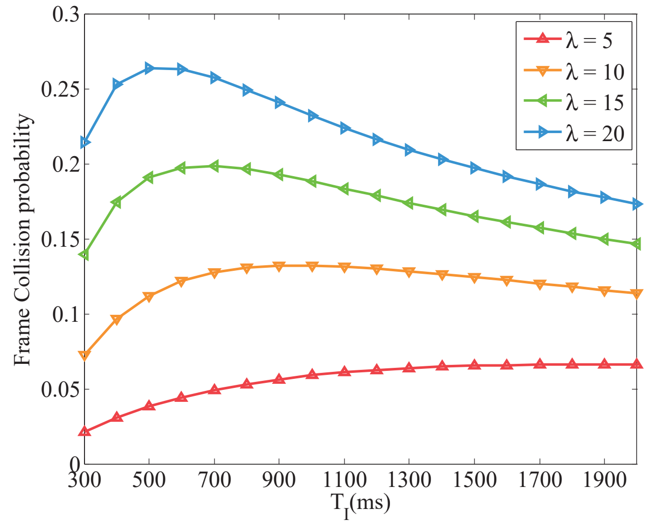

Fig. 4. Frame Collision Probability Versus λ and T_I

We also discuss the frame collision probability versus T_I and μ, by setting $\lambda = 20$ and $N = 10$ in Fig. 5. We observe that the frame collision probability decreases as μ increases. However, when $T_I \geq 1800$ms, T_I has a marginal impact on the frame collision probability, and the collision probability is mainly determined by μ.

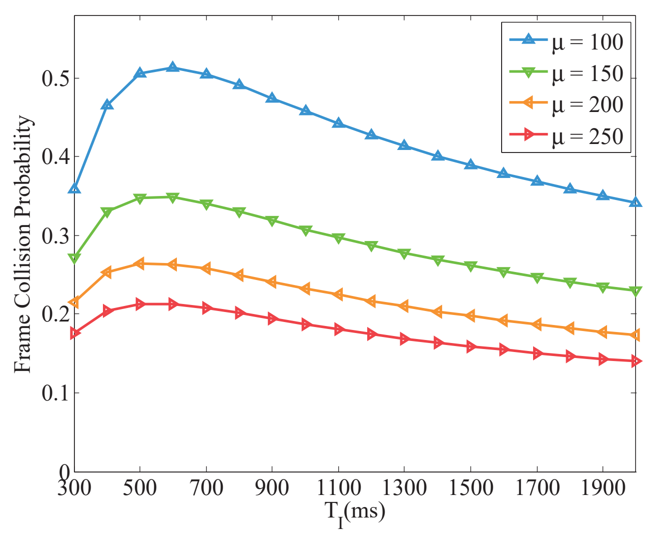

Fig. 5. Frame Collision Probability Versus μ and T_I

In addition, we study the the frame collision probability versus T_I and N, by setting $\lambda = 10$ and $1/\mu = 5$ms in Fig. 6. We could observe that the frame collision probability increases when N increases. However, as $T_I \geq 1500$ms, the frame collision probability from configuring T_I becomes smaller, and the collision probability mainly depends on N.

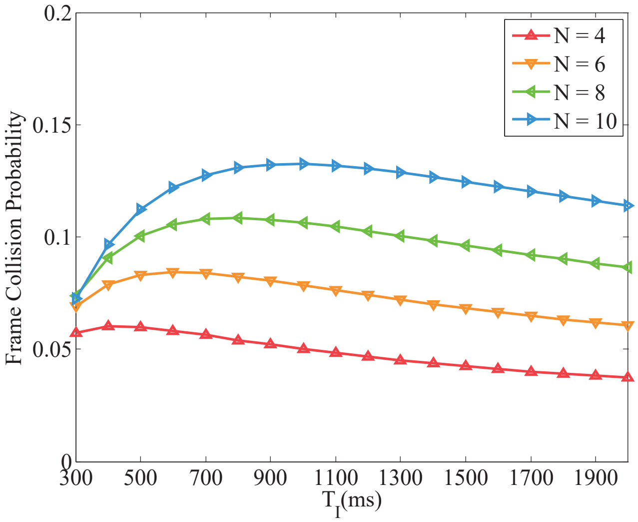

Fig. 6. Frame Collision Probability Versus N and T_I

C. Broadcast Overhead Analysis

In addition to the frame collision probability analysis, we also evaluate the broadcast overhead of IEEE 802.11bc network. Since IEEE 802.11bc network adopts the EBCS Info frame to broadcast the scheduling information for DL EBCS data frame, extra broadcast overhead will be introduced. We define the broadcast overhead as the broadcast number of the EBCS Info frame within 1s. When enlarging the EBCS Info frame transmission interval T_I, the broadcast number of the EBCS Info frame is reduced, i.e., the broadcast overhead could be decreased. Otherwise, the overhead is increasing.

Finally, based on the above frame collision and broadcast overhead analysis, we give the broadcast parameters configuration given the specified frame collision probability and broadcast overhead constraints, as shown in Table II.

TABLE II
BROADCAST PARAMETERS CONFIGURATION IN IEEE 802.11BC

Frame Collision Probability	Broadcast Overhead i.e, number/s	λ	μ	N	T_I(ms)
5 %	1	10	200	4	1500
10 %	1	10	200	8	1300
15 %	2	10	200	10	900
20 %	2	15	200	10	800
25 %	3	20	200	10	400
30 %	4	20	150	10	300

V. CONCLUSION

In this paper, we study the frame collision probability between DCF-based unicast data and scheduling-based broadcast data within the framework of IEEE 802.11bc. We study the tradeoff among station arrival intensity, broadcast and unicast frame collision, and broadcast control frame transmission interval. We derive an analytical model to quantify the above performance tradeoff. Based on this model and simulation results, we give the broadcast parameters configuration for the broadcast control frame transmission interval to balance the broadcast overhead and data collision.

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