Researches and Evaluation of Strong Busy Tone that Improves the Performance of Ad-hoc Networks

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***Abstract*—In IEEE802.11 standard, a method based on RTS and CTS is adopted as the method to solve the hidden terminal problem in ad-hoc networks. However, the throughput by this method greatly degrades when the traffic volume increases, because of the occurrence of collisions between RTSs or between CTS and DATA. Thus, we propose in this paper, we propose a method to improve the throughput of ad-hoc networks, by using a special control signal called "SBT" (Strong Busy Tone) based on the expanded that has expanded the reachable range of radio waves of conventional busy tones, and also by modifying the back-off algorithm of CSMA/CA.**

I. Introduction

Popularization of wireless LAN technologies has been rapidly advancing towards the realization of ubiquitous society, as wireless LAN does not require any wiring and the mobility of terminals is also secured.

Ad-hoc networks that enable direct communication between terminals are drawing attention, in particular. However, it is well known that ad-hoc networks are affected by the hidden terminal problem [1] quite often and as a result, the throughput greatly degrades along with the increase in the traffic volume.

In IEEE802.11 [2], a method based on RTS (Request to Send) and CTS (clear to send), is adopted as the method to solve the hidden terminal problem. The RTS/CTS method prevents collisions by placing terminals in the vicinity in a state of virtual carrier detection and by suspending their transmission for a certain length of time. However, with this method alone, we cannot avoid cases of collisions between RTSs or between CTS and DATA when the traffic volume is big. As the reason for such collisions, we can point out the problem that a certain length of time is required for a series of sequences, because RTS and CTS are in the form of packets themselves. Also if a collision occurs during the sequence of RTS/CTS, a so-called "exposed terminal problem" takes place in which terminals in the vicinity remain in the state of suspended transmission.

As a technology related to this paper, there has been a proposed method that improves the throughput by controlling terminals in the vicinity, using a control signal called "busy tones". Busy tone is a kind of radio waves of single frequency and is a control signal to convey to the terminals in the vicinity that the network is in a busy state at the moment. The busy tone has a feature that the amount of power to consume is quite small since its bandwidth is narrow. In addition, even if multiple devices produce busy tones simultaneously, devices in the vicinity are able to detect them. In [3]∼ [6], busy tones are used for the purpose of preventing influence of noise in the area where the noise is generated. However, they are not effective in solving the hidden terminal/exposed terminal problems. In [7]∼ [9], busy tones are used to solve the hidden terminal problem by starting to send busy tones at the time of sending RTS/CTS, but the effect seems to be limited to the terminals in the vicinity alone. In any event, its effectiveness is not clearly proven.

In this paper, we have reviewed the effectiveness of busy tones and propose a new throughput improvement method to solve both the hidden terminal problem and the exposed terminal problem at the same time. That is to say, we propose a system which uses so-called "Strong Busy Tone" (hereafter" SBT") [10]. SBT is a special busy tone whose area of coverage is much wider than that of conventional busy tones. In our proposed system, collision decreases drastically, and as a result, we can increase the throughput of the system. In addition, by using SBT, it becomes possible to shorten the value of the slot time Δt in the CSMA/CA algorithm, and consequently, we can further improve the throughput.

As SBT controls transmissions by terminals in the vicinity over a wide range, SBT becomes also a factor to lower the throughput of the entire system. Accordingly, we conducted a simulation-based evaluation by using ns-2 (Network Simulator 2), and compared the throughput of our proposed method with that of the method based on RTS/CTS. As a result, we found that in every case, our proposed method shows better communication performance.

Hereinbelow, we explain the existing methods and its associated problems in Section 2 and our proposed method in Section 3, examine the simulation and its results in Section 4, and finally summarize the conclusion in Section 5.

II. Existing Technologies and Their Associated Problems

A. Problems associated with RTS/CTS-based Method

We show some examples of problems associated with RTS/CTS-based Method in Fig.1 and Fig. 2. We show an example where Terminal A and Terminal C are in a relationship of hidden terminals each other, and communication is made from Terminal A to Terminal B. Fig. 1 shows a situation in which Terminal A and Terminal C start transmission to Terminal B almost simultaneously, and a collision between RTSs occurs. As it takes a certain length of time for the exchange of RTS/CTS, we cannot avoid this kind of situation. When a collision between RTSs has occurred, CTS is not sent back. Thus, both Terminal A and Terminal C need to resume transmission of RTS. The merit of RTS/CTS-base method is

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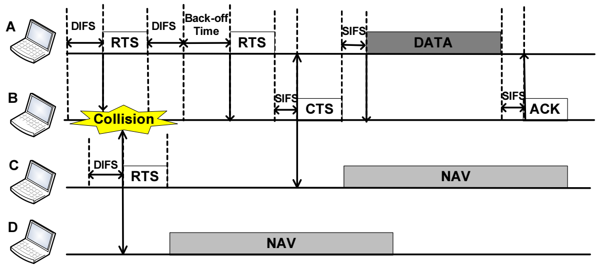

Fig. 1. Example of the problem associated with RTS/CTS

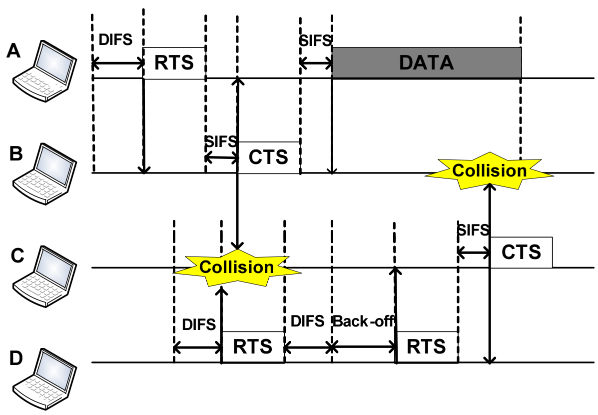

Fig. 2. Another example of the problem associated with RTS/CTS

that, we can avoid sending lengthy DATA in vain. On the other hand, Terminal D is placed in the state of NAV when it has received RTS and thus, it gets into an exposed terminal state. Moreover, as we mention in Section 2.2, because the length of time for the exchange of RTS/CTS is not negligible, it is a big factor to lower the throughput.

In Fig. 2, Terminal B sends back CTS against RTS sent by Terminal A, and gives approval for transmission. Here, if, during the exchange of RTS/CTS between Terminals A and B, remotely located Terminal D transmits another RTS, CTS of Terminal B and RTS of Terminal D collide at the position of Terminal C. As Terminal D does not receive CTS, it transmits RTS again. In the meantime, since Terminal A has received CTS from Terminal B, it starts DATA transmission towards Terminal B. As Terminal C sends back CTS to RTS of Terminal D, DATA of Terminal A collides with CTS of Terminal C. As a result, it becomes necessary for Terminal A to send DATA again. This situation is a factor to lower the throughput in the sense that the lengthy DATA are sent in vain.

The cause of these problems lies in the fact that it takes a certain length of time for the sequence of RTS/CTS, as the exchange is made in the form of packets.

B. Problems Attributable to PLCP

The time required for the exchange of RTS/CTS is not negligible. As the reason for that, we can name the overhead of PLCP (Physical Layer Convergence Protocol). PLCP is a physical header, which is indispensable at the time of sending packets wirelessly. PLCP is composed of a PLCP preamble

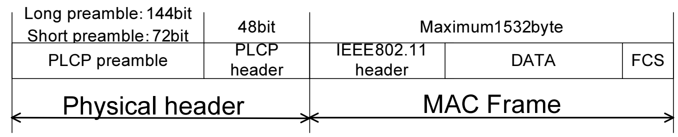

Fig. 3. Format of PLCP

TABLE I. TIME REQUIRED FOR EACH SEQUENCE

IEEE802.11g	time(μs)	
	PLCP	Main frame portion
DIFS		34
RTS	26	3
SIFS		10
CTS	26	3
DATA(Maximum length)	26	227
ACK	26	3

and a PLCP header, both of which are attached in front of IEEE802.11 MAC header, as shown in Fig. 3. In the PLCP preamble, information necessary for the receiving terminal to establish synchronization is described, and in the PLCP header, information related to the speed of MAC frame is defined.

Taking IEEE802.11g as an example, while the maximum communication speed of the MAC frame portion is 54 Mbps, the speed of the PLCP portion is set at 2 Mbps so that all terminals can receive communication. For that reason, there are cases where the PLCP portion takes far longer time than the MAC frame portion. PLCP is added not only to DATA but also to other frames such as RTS, CTS and ACK. Table I shows the times required for a series of sequences in IEEE802.11g. As seen from Table I, while MAC portion of RTS, CTS and ACK takes about 3μs only, PLCP portion takes as long as 26μs. Although the MAC frame structure of RTS/CTS is defined short, we can see that the time required for transmitting the packets is very long as a whole. As a result, in addition to the situation where the exchange of RTS/CTS becomes overhead, the possibility of collisions taking place between hidden terminals gets high.

C. Busy Tones

Technologies to improve the throughput by controlling terminals in the vicinity based on busy tones have been proposed. In [3]∼ [6] prevents the influence of noise by adjusting the reachable range of busy tones in conformity with the range of noise occurring at the time of communication. In wireless communication, noise occurs at the time of communication and the degree of noise increases in proportion to the distance of communication. Although a terminal starts communication when no carrier is detected in the vicinity, the possibility of errors increases in the case of long distance communication because of the influence of noise. Thus, by transmitting busy tones to the maximum range of noise occurrence at the time of starting communication, the terminal controls other terminals in the vicinity. The range of busy tones is dynamically adjusted, by narrowing the range if no error occurs, or expanding it if error occurs. The aim of this technology is, however, to prevent the error due to the noise of wireless communication and it has no effect on the hidden terminal/exposed terminal problems.

In [7]∼ [9], a method to solve the hidden terminal problem

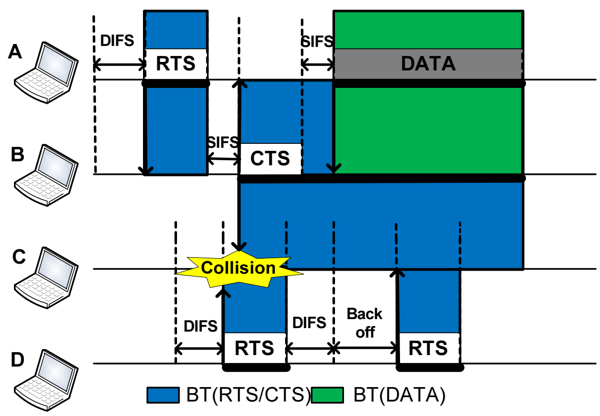

Fig. 4. Resolution of the problem based on the existing busy tone technology

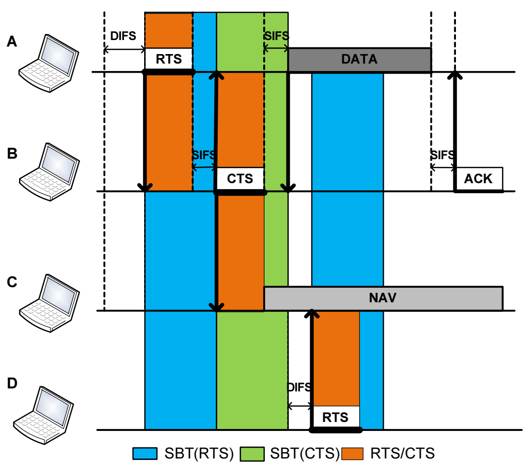

Fig. 5. Operation of SBT

by sending busy tones to RTS/CTS is proposed. Fig. 4 shows its mechanism. Terminal A inhibits communications by other terminals in the vicinity at the time of sending RTS and DATA, by transmitting busy tones at the same time. Terminal B transmits busy tones at the time of sending back CTS, and continues transmitting the busy tones until completing the receipt of DATA. With this method, a collision between DATA of Terminal A and CTS of Terminal C at the position of Terminal B, shown in Fig. 2, can be avoided. However, this method cannot prevent the collision between RTSs, in the case shown in Fig. 1 and that between CTS of Terminal B and RTS of Terminal D at the position of Terminal C, in the case shown in Fig. 2. Furthermore, because no evaluation based on the network simulator has been made, its quantitative effectiveness has not been made clear.

III. Our Proposed Method

In this paper, we first introduce SBT, a new type of busy tones, and next, we propose a method to shorten the slot time of CSMA/CA, which is made possible through the introduction of SBT, in order to solve the problems associated with existing technologies.

A. Introduction of SBT

SBT is a control signal that has expanded the reachable range of radio waves of the conventional busy tones so as to control remotely located terminals as well. When each terminal sends RTS and CTS, it sends SBT at the same time. Then, other terminals cannot start new communication when they have detected SBT. However, if they are already in the course of communication, they simply ignore SBT even if they have detected it.

Fig. 5 shows the operation of SBT at the time when the system is introduced. Terminal A, at the time of its sending RTS, simultaneously transmits SBT by expanding by 3 times the reachable range of radio waves so that it can also reach Terminal D. Then, Terminal B, at the time of its sending CTS, simultaneously transmits SBT by expanding by 2 times the reachable range of radio waves so that it can reach Terminal D. Terminal D cannot start transmission while it is receiving SBT. Through this method, we can avoid collisions of packets, as indicated in Fig. 1 and Fig. 2. Fig. 5 shows the case where Terminal D sends RTS right after the transmission control by SBT had ended. Terminal C is already in the state of NAV after receiving CTS from Terminal B. Thus, Terminal C does not send back CTS, and the transmission from Terminal A can end in an ordinary manner. Under the control of SBT, the transmission of useless RTS is greatly suppressed, and the possibility of exposed terminals are significantly decreased. On that occasion, although the SBT transmitted by Terminal D also reaches Terminal A, Terminal A ignores it as the Terminal is already in the process of transmission, and no impact is given on the transmission of DATA.

B. Shortening of Slot Time

By introducing SBT, shortening of slot time (Δt) at CSMA/CA algorithm becomes possible, and by shortening Δt, it becomes possible to reduce the waiting time of back-off process and to improve the throughput. The back-off time in CSMA/CA at the time of retransmission is determined according to the following formula.

$$\text{Back-off Time}=\Delta t \times r(\text{CW})$$

Here, Δt means slot time, r means random numbers 0∼CW, and CW means the contention window size. CW changes in the order of 15, 31, 63, 127 and so forth, according to the number of collisions, and the highest value is 1,023. Δt is the time of minimum unit required for calculating the back-off time, and it is defined as 9 μs by IEEE802.11g. The breakdown of 9μs is defined as follows.

$$\Delta t = \text{CCA Time} + \text{Air Propagation Time} + \text{RxTx Turnaround Time} + \text{MAC Processing Delay}$$

- CCA Time : Status judgment time (4μs)
- Air Propagation Time : Propagation time (1μs)
- RxTx Turnaround Time : transmitting/receiving switching time (2μs)

- MAC Processing Delay : MAC's processing time (2μs)

These values are determined on the assumption that the transmitted information is in the form of packets. Here, if we assume implementation of a control based on SBT, we can delete unnecessary items. "CCA Time" is the time required in judging whether the terminal is in a transmitting state or in a receiving state. This value can be deleted, as it can be judged that other terminals than that in the transmitting state are all in the receiving state, as a result of the use of SBT. "Air Propagation Time" is the propagation time of radio waves. This is necessary in conducting communication and thus, we cannot delete it. "RxTx Turnaround Time" is the time required for switching the state of transmitting/receiving on a hardware basis. Because this process is necessary at the time of transmission, we cannot delete it, either. "MAC Processing Delay" is the time required by MAC to perform its processing. We can delete it because when SBT is used, MAC's processing time is quite short, since SBT is a kind of radio wave which does not contain any information.

From the facts as mentioned above, in our proposed method, it is necessary to consider merely the propagation time (Air Propagation Time) of SBT and the time required for switching the state of transmitting/receiving (RxTx Turnaround Time).

The propagation time is about 0.3μs, if we assume the distance between two terminals is 100 m. As it is necessary for the control by SBT to control up to the distance of 3 hops away at the maximum, we can define the time required for SBT to reach 3 hops (300 m) away as the Air Propagation Time. In our proposed method, we define it as 1μs by allowing some margin. Thus, in our proposed method, we can shorten the value of Δt to "3μs", which is the total of Air Propagation time (1μs) and RxTx Turnaround Time (2μs).

IV. Simulation

By applying SBT, we are able to reduce the possibility of collisions drastically, but it becomes also a factor to degrade the throughput of the entire system, as it inhibits transmissions by terminals in the vicinity over a wide range. Thus, we examined degree of the effectiveness of reducing the collisions by ns-2 and also that of shortening the slot time.

A. Simulation Environment

Table II shows parameters of the entire measurement environment and Table III shows the parameters of TCP/UDP communication. We assumed that the packet's reachable range is 100 m, and SBT's reachable range is 300 m at the time of sending RTS and 200 m at the time of sending CTS. FTP is adopted as TCP's communication type, and the packet size is set at 1,000 Byte. VoIP (Voice over Internet Protocol) is assumed for UDP, and CBR (Constant Bit Rate) is adopted as UDP's communication type, and the packet size is set at 200 Byte, and packet generating rate is set at 64 kbps.

We made a comparison regarding the following 3 Cases. Table IV shows the communication method for each Case.

- Case1: Communication by existing technology based on RTS/CTS

TABLE II. Parameters of the measurement environment

Access method	IEEE802.11g
SBT(RTS) reachable range of radio waves(m)	300
SBT(CTS) reachable range of radio waves(m)	200
Field	300×300
Propagation method	Two Ray Ground
Antenna type	Omni Antenna
Routing protocol	AODV
Measuring time(s)	330
Wireless bandwidth(Mbps)	54

TABLE III. Parameters of TCP/UDP communication

TCP communication	Communication type	FTP
	Transport protocol	TCP
	Packet size(Byte)	1000
UDP communication	Communication type	CBR
	Transport protocol	UDP
	Packet size(Byte)	200
	Packet generating rate(kbps)	64

- Case2: Communication applying SBT alone
- Case3: Communication with shortened Δt, in addition to applying SBT

Fig. 6 shows the simulation environment. A total of 37 terminals at intervals of 90 meters were placed in a mesh shape, so that the radio wave from each terminal reaches other terminals existing within one hop away. As shown in Fig. 6, for the purpose of measurements, Terminal 12 is used as the sending terminal and Terminal 32 as the receiving terminal, and TCP communication is conducted between these terminals. As the background load, UDP communication is conducted by all terminals except for Terminals 12 and 32. In that case, the pairs of sending and receiving terminals are chosen on an at-random basis from the remaining 35 terminals. TCP communication is started after 20 seconds from the start of simulation. At that moment, only one TCP session subject to the measurement is established. Thereafter, the pairs of terminals selected on an at-random basis establish UDP session one after another at intervals of 5 seconds. In this way, the background load has gradually increased. We measured how the throughput of TCP communication changed in accordance with such gradual load increase. As regards the UDP communication to be conducted as the background load, we assumed that 60 pairs of UDP communication at the maximum was performed.

B. Measurement Results

Fig. 7 shows the results of the throughput measurement of TCP communication. The horizontal axis indicates the number of terminal pairs used as the background load and the vertical axis the measurement of TCP throughput. Fig. 8 shows the changes in the number of collisions. The horizontal axis indicates the number of terminal pairs used as the background load and the vertical axis indicates the number of collisions. Fig. 9 shows the total of UDP background traffic. The horizontal axis indicates the number of terminal pairs and the vertical axis indicates total UDP throughput. The results shown here are based on the average values of 20 times of experiments.

TABLE IV. COMMUNICATION METHOD FOR EACH CASE

	Use of SBT	$\Delta t(\mu s)$
Case1	No	9.0
Case2	Yes	9.0
Case3	Yes	3.0

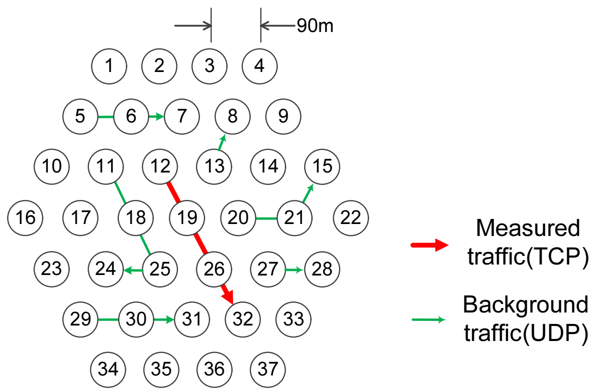

Fig. 6. Simulation environment

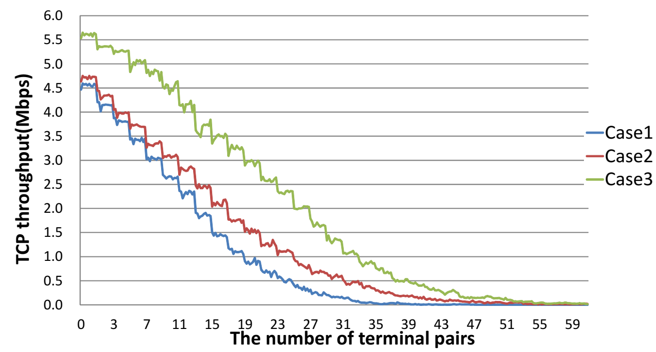

Fig. 7. Results of measurements of TCP communication throughput

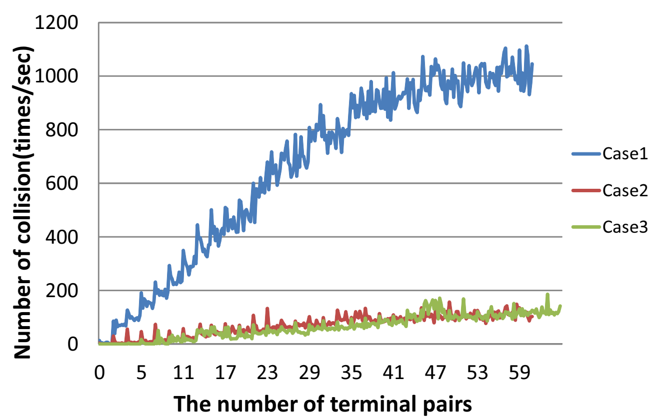

Fig. 8. Changes in the number of collisions

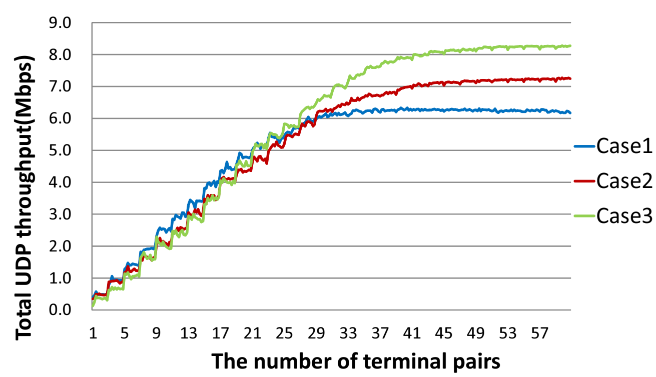

Fig. 9. The total of UDP background traffic

From Fig. 7, we can see that in proportion as the amount of background load increases, TCP throughput gradually goes down. This is because the background load of UDP occupies part of the traffic. We can see that in proportion as the number of terminals used for the background load increases, degradation of the throughput is prevented by using SBT, compared with the existing method. Furthermore, we can see that by shortening Δt, the value of the throughput greatly increases. If we make a comparison under the situation where UDP background load occurs at 31 pairs of terminals, TCP throughput is considered to improve by about 10 times compared with the existing technology. Furthermore, Case 3 always shows higher values compared with Case 2, and we can see that even under the situation where communication protocols coexist, we can get a positive effect from the shortening of Δt.

From Fig. 8, we can see that the number of collisions significantly reduces in both Case2 and 3 as compared to Case1.

From Fig. 9, total UDP throughput increases according to the increase of the number of UDP terminal pairs. At the point of 29 in terminal pairs, the increase of total UDP throughput stops in Case1 because of the saturation of the network. On the network. On the other hand, it still increases in Case2 and Case3. It can be understood that SBT contributes the utilization rate of the network. From the above-mentioned results, we could confirm that our proposed method is very much effective even in the TCP/UDP coexisting environment (namely, the degree of effect of preventing collisions by SBT largely exceeds the degree of effect of inhibiting transmissions.)

V. Conclusion

In order to solve the problems associated with the RTS/CTS-based method, we have proposed a method to drastically decrease the number of collisions by introducing SBT and also to reduce the transmission waiting time by shortening the slot time Δt. Based on a simulation, we have verified a large improvement in the throughput in the TCP/UDP coexisting environment. We confirmed that despite the fact that SBT has a feature of inhibiting transmissions by other terminals in the vicinity, a far larger positive effect is gained from preventing the occurrence of collisions. We confirmed, in particular, that the effect of shortening Δt is very large.

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