CSMA/CD WITH RESERVATIONS IN WIRELESS COMMUNICATION: A NOVEL APPROACH TO RESOLVE COLLISIONS

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ABSTRACT

This paper proposes a medium access protocol, CSMA/CD-R (Carrier Sense Multiple Access/Collision Detection with Reservation), designed for wireless network mobile robots under a distributed robot system without any centralized mechanism. It employs stations to reserve a communication channel after communication collision such that it shows better performance than conventional CSMA protocol for the wireless communication of the distributed robot system. The effectiveness and applicability of the proposed protocol are demonstrated by carrying out computer simulations and real experiments with the robot soccer system.

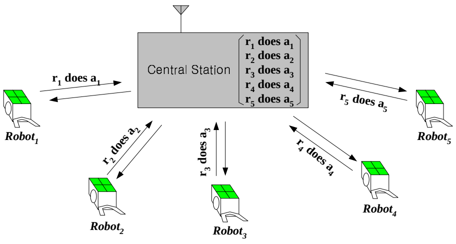
1. INTRODUCTION

The objective which develops a mobile robot system is to reduces the necessity of the person in minimum from a dangerous place which are, for example, to dispose the dangerous waste, repair the nuclear power plant, explore the different planet, rescue the people, search building or the dangerous area. And simple, repeat works, for example, automation production facility or the factory equipment maintenance are fields where the mobile robot system is necessary. The fact which is demanded from this field is a the robot system which accomplish the demand of the person and fully automated. Namely, it is to make the autonomous robot which is able to accomplish a work from given environment. However, in the case of a single autonomous robot, adaptation power which accomplishes various tasks in various environments is lower than a multi robot system. Also, sometimes there is time limit to accomplish tasks and to make a multi robot system which consists of many simple robots is more economic and easier than a complex autonomous robot which is able to accomplish all tasks. So, recent research regarding the mobile robot is treating about the strong point of multi robot system. For a multi robot system, the embodiment principal of the intelligence control should be determined and the cooperation mechanism with which the robots will act independently inside that system and simultaneously cooperate with each other should be supplied.

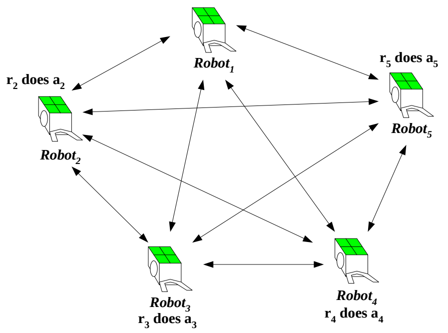
In the view of communication and cooperation of a multi robot system, researches can be divided into two branches, using explicit communication and cooperation and not using them. First of all, in order to cooperate explicitly, the robot system knows the existence of other robots and communicates with them and cooperate. This explicit and direct communication is researched by Caloud et al. (1990), Noreils (1992), Parker (1993), and etc.

In case of not doing a explicit cooperation (implicit cooperation), a robot does not recognize other robots and it cooperate implicitly with other robots which have same purpose. This research is accomplished by Dallas (1990), Kube (1992), and etc. Each robot is able to accomplish not only a task autonomously but also the task which is impossible for a robot to accomplish by itself using communication. As shown in Figure 1, the central computer or the share memory or the synchronous signal are not allowed in the distributed robot system. In other words, it consists of the mobile robot and an auxiliary method like a central computer is not used.

The token ring method or the carrier sense multiple access method which are representative communication methods in a multi robot system is one of the basic time division multiplexing communication method. In the frequency division multiplexing, every robot is allocated by frequency resources but communication channel is limited, so when the robot system becomes larger, it is difficult to apply. In the efficiency side, the Token ring method is superior. However, when only a robot breakdown, the next robot does not



(a) Centralized communication system



(b) Distributed communication system

Figure 1: The comparison of communication system

share information. Also, because it gives a communication ID to the robot and pass over the right of a channel good sequentially, it has not a good ability in the expandability like addition or removal of the robot. So, the carrier sense multiple access is more proper for a distributed robot system.

Two problems should be solved for a CSMA protocol (which is originated for Ethernet) to operate over a wireless communication under the distributed robot system. First, since no centralized mechanism or ground support is allowed, existing variations of CSMA/CD (Carrier Sense Multiple Access/Collision Detection) relying on a centralized mechanism to detect and to indicate a collision can not be used. Second, for an autonomous mobile robot to detect collision on the shared radio communication channel, both its transmitter and receiver must be operating at the same time. Since the antennas for the transmitter and that for the receiver can not be placed so far apart on the mobile robot, the radio energy emitted by the transmitter is so overwhelmingly strong relative to that emitted by other robots at distances that the detection on simultaneous transmissions on a shared radio communication channel is practically impossible.

In this paper, CSMA protocol is improved by allowing stations to reserve a channel after collision, and in this way to succeed transmission. A medium access protocol, CSMA/CD-R (Carrier Sense Multiple Access/Collision Detection with Reservation), designed for wireless network mobile robots under a distributed robot system (without a centralized mechanism) is proposed, which solves these two problems.

The reminder of the paper is organized as follows. In section 2, the mechanism of the CSMA/CD-R protocol is described. In section 3 and 4, a computer discrete event simulation and the experimental results are presented. The conclusions are finally drawn in section 5.

2. WIRELESS MEDIUM ACCESS PROTOCOL

2.1. Assumptions and Definitions

In this section, related assumptions and notions to propose the CSMA/CD-R are described.

- In this paper, a distributed robot system is considered. a same communication system is implemented on every robots and auxiliary devices such like a relay computer are not allowed. Existing CSMA protocol is designed to control a channel by a centralized communication server, so it should be modified to use in a distributed robot system.

- All communication systems are half-duplex in which transmission receive are both possible but not simultaneously. This limit is usual for off-the-shelf wireless communication system and because it can not receive during transmission, other transmission can not be recognized. However, the switch between transmission and receive is possible by external device.

- In this paper, only one communication channel is allowed for communication. Most of off-the-shelf communication module are fixed at specific frequency and also frequency resource is limited, so distinct frequency can not be assigned to every robots. Moreover, if each different frequency allocates to each robot, the receiver which receive all frequencies should be implemented.

- The size of transmission data packet is fixed, and a data from a robot can be distinguished with that from the other. When communication packets from more than two robots send simultaneously is received, it can not be analyzed like a noise and can be distinguished.

A mobile robot constitutes a *node* in the wireless communication network. A single radio communication channel is used as a multi access medium shared by all nodes. Only one node should transmit at any given time. Simultaneous transmissions from more than one node cause a *collision*.

Consider a slotted system whereby time is divided into fixed length intervals. Each of these time intervals will be called a *slot*. The purpose of the slotted system assumption is to simplify the explanation and simulation of this new protocol.

Let T be the duration of a slot. All stations in the network are synchronizes so that a packet transmission is always commenced at the beginning of a slot. Henceforth, I shall use the concept of slot to refer also to the amount of data [bits] which can be transmitted within a time slot. Packet length may be variable, but it must be padded as in Ethernet [1] so that it is equal to an integer number of slots.

Let τ denote the maximum propagation delay between any two stations in the network and the minimum duration of a slot is $T = 2\tau$. In addition, the channel is sensed idle by all stations τ units of time after the end of a successful transmission, and a successful transmission is detected τ units of time after it is started.

2.2. Carrier Sense Multiple Access/Collision Detection with Reservation (CSMA/CD-R)

A single radio communication channel is used as the raw medium for all nodes. To reduce the probability of simultaneous transmission (collision), a node checks the status of the shared communication channel before a transmission is attempted. If the channel is busy, it waits for a random period of time.

There is nevertheless still a small chance for two or more nodes to start transmission at almost the same time, which results a collision. Due to strong radio energy emitted by the transmitter, it is impossible for a node to detect and realize the collision until the transmission is completed.

The protocol is designed such that the length of a message generated by a node is always fixed, and is distinct from that generated by others. Thus if a collision occurs they will end their respective transmission at different time moments.

For this, novel wireless communication protocol, CSMA/CD-R (Carrier Sense Multiple Access/Collision Detection with Reservation) is proposed as shown in Figure 2.

- CD (Channel status): it defines the status of a communication channel.

$$CD = \begin{cases} 1 & \text{if a channel is used by more than a node,} \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

- VOC (Validity of Carrier): it defines the validity of a communication channel. The received signal is valid if modulated signal from the transmitter can be demodulated (i.e. the received signal must have been emitted from a single node).

$$VOC = \begin{cases} 1 & \text{if a signal from the transmitter can be} \\ & \text{demodulated,} \\ 0 & \text{otherwise.} \end{cases} \quad (2)$$

- $CR - R$ (Collision Report with Reservation): it is a acknowledge signal from nodes after collision. By this signal, a robot can decide a the order of priority and re-transmit in order.

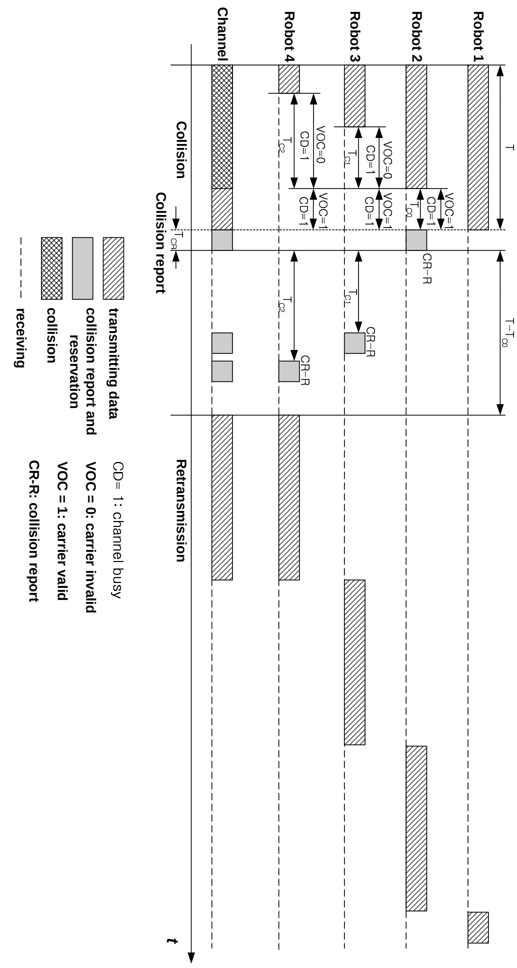


Figure 2: Example of CSMA/CD-R

- T_{cn}: it is a time from the transmission of a robot to receive a valid signal (a signal from a single robot). n is a order which recently finishes the transmission. A robot which finish the last transmission, can not recognize a collision, so from the robot which ends transmission lately at the second measure T_{cn}.

Our proposed CSMA/CD-R protocol is an extension of the CSMA/CD protocol described by the following rules.

1. If the channel is sensed idle ($CD = 0$), a ready node transmit its packet immediately. It is required to monitor the channel status in case of a collision.

2. If the channel is sensed busy ($CD = 1$), a ready node keeps monitoring the channel status. As soon as the channel becomes idle, the ready node transmits its packet into the next slot with probability one.

There is nevertheless still a small chance for two or more nodes to start transmission at almost the same time, which results a collision. After detecting a collision, its packet should be re-transmitted. By CSMA/CD-R protocol, the following rules are proposed for a collision.

1. After transmitting a packet, if a packet is received, it is assumed to be collided.
2. With a collision, if a signal is from more than two nodes, it can not be translated ($VOC = 0$). In this case, it can be measured, T_{cn}, a time from the transmission of a robot to receive a valid signal (a signal from a single robot).
3. With a collision, if a signal is from a node, it can be translated ($VOC = 1$). In this case, a collision report ($CR - R$) should be transmitted after a collision.
4. After a collision (after receiving a $CR - R$), each node transmit a $CR - R$ in T_{cn}.
5. After ($T - T_{c0}$), a node transmit its packet according to a sequence of transmitting a $CR - R$, i.e. a node which transmit a $CR - R$ later, transmits its signal first.

Figure 2 shows that four nodes (Robot1, Robot2, Robot3, Robot4) transmit simultaneously (collision). Each node checks a communication channel after a transmission. If a channel is used for a transmission ($CD = 1$ as shown in Figure), it is known that a collision was happened and other node is transmitting a signal. However, a latest node which transmit a signal latest can not recognize which a collision happens or not. Thus, other node has to send a collision report by which a latest node knows about a collision. In Figure 2, Robot2 recognizes a communication channel is used by another node after it finishes a transmission and switches from a transmission mode to a reception mode. In this manner, a validity of channel, VOC, should be checked after a transmission by each node. If a signal which is received through a channel can be translated, it may be considered as a signal from a single node and in this case, VOC becomes 1. However, when Robot3 checks a communication channel after a transmission, it is known that Robot1 and Robot2 transmit simultaneously and a collision happens. Thus, if a received signal can be translated, i.e. it is different from pre-determined communication protocol, it means that more than two nodes are transmitting signals simultaneously and VOC equals zero. As already mentioned, a latest node which transmit a signal latest (Robot1 in Figure 2), can not recognize a collision, so a second latest node (Robot2) should send a collision report, $CR - R$, which is a pre-defined signal for a latest node (Robot1) to recognize a collision.

Each node which collides with others, measures a duration time (a period with $VOC = 0$) from a collision, T_{cn}. In Figure 2, each node waits for T_{cn} after Robot2 send a collision report and then send its $CR - R$ and count which number of its $CR - R$ is. Robot3 waits for T_{c1} after receiving a first $CR - R$, and send its second $CR - R$. Robot4 waits for T_{c2} after receiving a first $CR - R$, and send its third $CR - R$. Because there is no more $CR - R$ while all nodes wait for $T - T_{c0}$, a latest node, Robot4 transmits a communication packet first. Then, Robot3, Robot2 and Robot1 transmits its communication packet.

With this CSMA/CD-R protocol, all nodes can arrange for $T - T_{c0}$ and retransmit after any collision.

There are several merits in proposed communication protocol as listed below.

- This CSMA/CD-R communication protocol is suited for a distributed robot system, because there is no external and central device. It means that a robustness which is a major merit of a distributed robot system, can be maintained.
- In the view of scalibility, a specific number or any way for identification is used when each node uses a communication channel. Any node can use a communication channel at anytime and a robot can be added and extracted without any bad influence for a total robot system. Theoretically, there is no limit to scale.
- A existing wireline centralized communication protocol, CSMA/CD is modified for a wireless communication protocol for a distributed robot system.
- After a collision, each node can retransmit its signal as a priority (First In First Out), so a CSMA/CD-R protocol is superior to CSMA/CD.
- Because a CSMA/CD-R is a asynchronous protocol, it is not necessary for synchronization.

2.3. Design of Protocol

A receive process is to check a signal from a communication module. With analysis of a received signal, it should be determined which is a pre-defined data signal and which is a collision report ($CR - R$). Figure 3 shows a flow chart for a receive process.

If a received signal has a pre-defined frequency (418/433MHz in this paper), a status of a channel can be decided with a carrier detect (CD) of a communication module, busy ($CD = 1$) or idle ($CD = 0$).

If a signal is sent to a micro-processor and has a pre-defined protocol, then it is sent to a next process with VOC becoming 1. If a collision report, $CR - R$ or a noise is received , VOC becomes 0. A signal sent to a micro-process should be determined which is a signal packet or a $CR - R$, then sent to a next process. If a $CR - R$ is received, $Receive\_CR - R$ becomes 1. If a signal packet is received, a necessary data is extracted and sent to a robot.

A transmit process is to send a signal through a communication module (channel). However, if more than one node tries to transmit its signal, there maybe a collision. A signal contains a communication packet to other robot or a collision report for a acknowledgement signal. Figure 4 shows a flow chart for a transmit process.

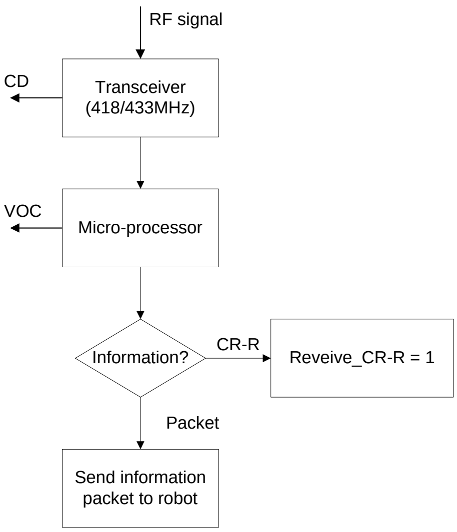


Figure 3: Flow chart of a receive process

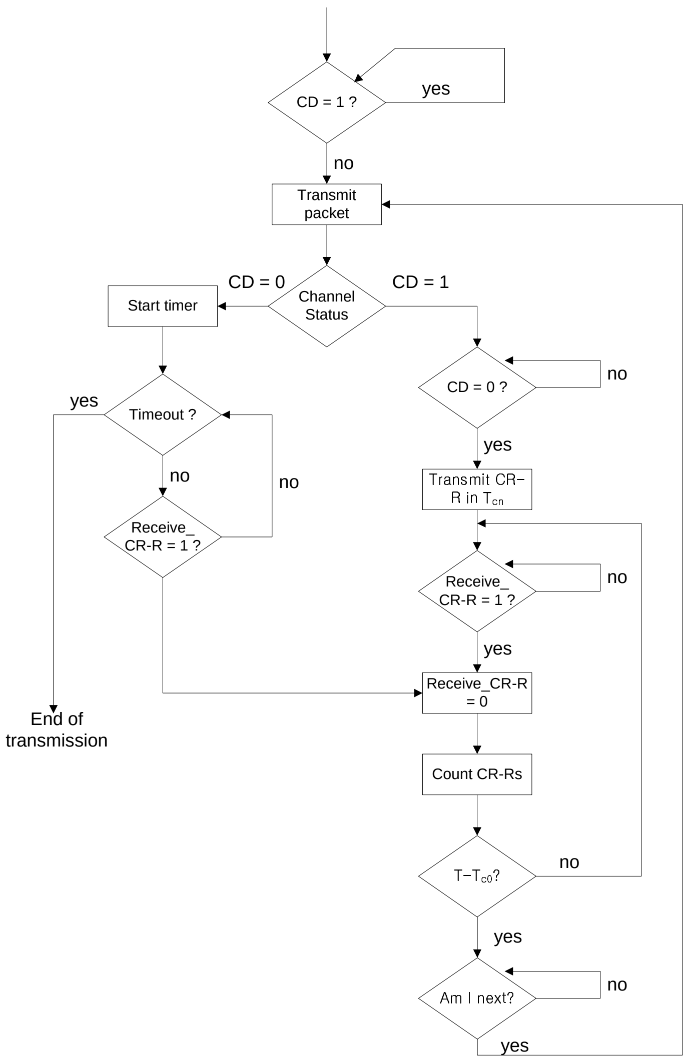


Figure 4: Flow chart of transmit process

A transmit process contains three parts. The left part of a flow chart in Figure 4, is to decide a usage of channel (CD) and transmit a signal if a channel is idle ($CD = 0$). If a channel is valid after a transmission, it means that there is no collision or a node transmit for the last time. If $CR - R$ is not received within T_{CR-R}, ($Receive\_CR - R = 0$), there is no collision and a node finishes a transmit process. If there is a collision and a node transmits for the last time, a node which transmits for the second last time, send a $CR - R$. Other node can receive this $CR - R$ and executes the right part of its flow chart. This right part represents a process after a collision. Each node, n, transmits a $CR - R$ in T_{cn}. The second latest node transmits a $CR - R$ at the moment that CD becomes 0. The latest node, as already explained, does not send a $CR - R$ and receives a $CR - R$ from other node.

Each node can decide its order by counting $CR - R$s from other node after transmitting its $CR - R$. If a node receive no $CR - R$ during $T - T_{c0}$, it retransmits first. Then, a node which receive a $CR - R$, retransmits. Thus, all nodes can retransmit its communication packet with the order of priority after a collision.

3. SIMULATION

Since the appearance of the Ethernet protocol [1] in mid 70, it has been extensively analyzed. The Ethernet protocol is based on 1-persistent Carrier Sense Multple Access with Collision Detection (CSMA/CD) with Truncated Binary Backoff (BEB) retransmission algorithm. Molle [3] has developed an approximate model to analyze BEB. In this section, his results are incorporated into the analysis of the CSMA/CD and CSMA/CD-R protocols.

The saturation scenario represents a continuous overload condition. The results of this scenario indicate a fundamental limit of a protocol - its performance for a given number of stations. Whereas, the disaster scenario [4] models the response of a protocol to the recovery (power up) from a major failure. This situation is likely to occur in the local area networks when the shared channel in the network is temporarily inaccessible due to, for example, a broken cable of a long period of noise. In this section, the simulation results of the two scenarios and comparison of them with the above analytic results are presented. As assumed before, the channel is slotted with the duration of each timeslot which equals twice of the propagation delay. A fixed packet size is considered. Furthermore, the following parameters are used in the simulation experiments.

Channel bit rates	38.4kbps (26μs bit time)
Propagation delay, τ	104μs
Slot time	2 τ
Packet size, T	5 slots (1040μs), 25 slots (5200μs)

First, a relation between a collision node, n and a channel throughput, S in the saturation scenario is simulated. Figure 5 shows the simulation results in the case of $T = 5$.

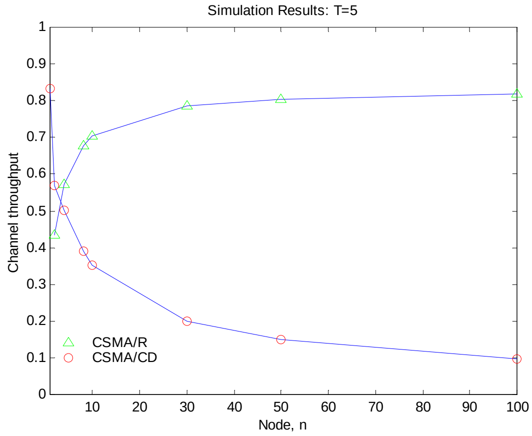


Figure 5: The comparison of a channel throughput in the saturation scenario ($T = 5$)

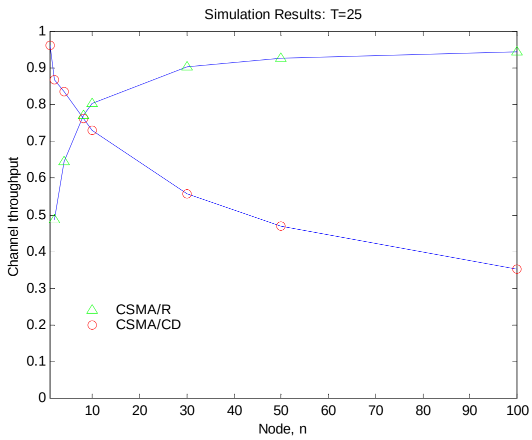


Figure 6: The comparison of a channel throughput in the saturation scenario ($T = 25$)

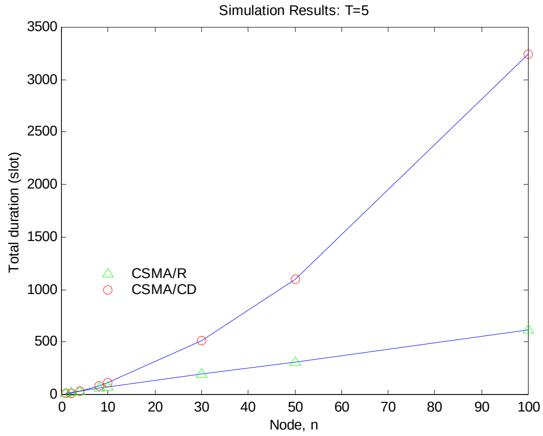


Figure 7: The comparison of a total duration in the disaster scenario ($T = 5$)

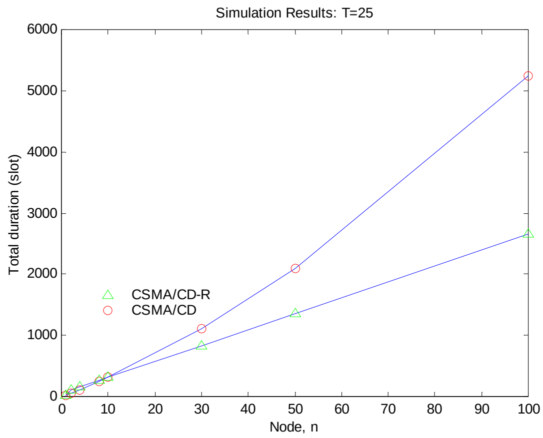


Figure 8: The comparison of a total duration in the disaster scenario ($T = 25$)

When a small number of nodes collides, a channel throughput in a CSMA/CD protocol is higher than in a CSMA/CD-R. On the other hand, a CSMA/CD-R shows increasingly superior performance to CSMA/CD as the number of collisions increases. Figure 6 shows the simulation results in the case of $T = 25$.

In these figures, settling values are 0.83 when $T = 5$ and 0.96 when $T = 25$. A channel throughput increases with n in the first part. This comes from a fixed contention time in CSMA/CD-R. As n increases, the effect of a fixed contention time reduces and a channel throughput converges to a settling value.

A relation between a collision node n and a total duration T_D in the disaster scenario is simulated. T_D in a CSMA/CD protocol is proportional to a square of n. However, in a CSMA/CD-R protocol, proportional to a n linearly. Figure 7 shows simulation results in the case of $T = 5$. When a small number of nodes collides, the total duration in CSMA/CD is relatively small. However, the total duration increases abruptly as the number of collision increases. On the other hand, CSMA/CD-R is superior to CSMA/CD as the number of collision increases. Thus, CSMA/CD-R has the advantage of scalability over CSMA/CD. Figure 8 shows the simulation results in the case of $T = 25$.

In this section, CSMA/CD and CSMA/CD-R are compared through various simulations. Consistent with the numerical analysis, the simulation results show that CSMA/CD-R is superior in the scalability aspect. However, CSMA/CD protocol is more effective in small-size systems. This is due to to the fixed time in CSMA/CD-R, $T - T_{c0}$, during which a node would wait its turn order of priority. Nevertheless, CSMA/CD cannot guarantee the *first-in-first-out* and scalability.

4. IMPLEMENTATION OF CSMA/CD-R PROTOCOL

There are two parts in a robot communication hardware, namely a transceiver (communication) module and a microprocessor. A transceiver can transmit or receive a signal,

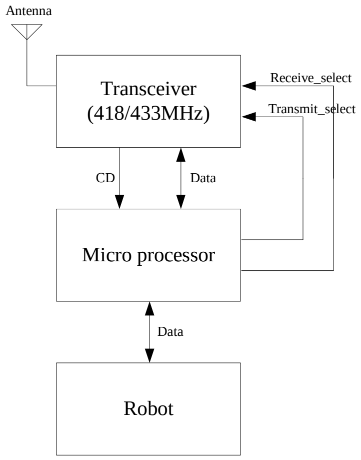


Figure 9: A concept of a communication circuit

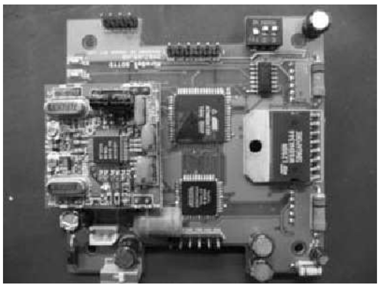


Figure 10: Implementation of a communication part

i.e., it is half-duplex. Thus, it takes some time to switch from a transmit mode or a receive mode to another. It is fixed at a specific frequency. In this work, a 424MHz or a 447MHz frequency module was used.

A microprocessor controls a signal from or to a transceiver module. It is an interface between a higher robot control system and a transceiver, and controls the mode switch of the transceiver. The following signals were controlled by a microprocessor for CSMA/CD-R communication:

- CD (Carrier Frequency Detected): A boolean. If a channel is used, it becomes 1. To check this value, a microprocessor always observes a receiving signal.
- VOC (Validity of Carrier): A boolean. If a received signal is from only a node, VOC becomes 1. If it is from more than a node, it becomes 0. To decide VOC, a microprocessor always observes a receiving signal and if the signal has a pre-determined protocol, it is assumed to be received from only one node.

Figure 9 shows a circuit that can transmit or receive a signal, check the above two signals and switch the mode of a transceiver module. Because a transceiver module is half-duplex, logic 1 is set at the control pin for transmission or reception. Figure 10 shows a communication part and a circuit implemented in soccer robots (SOTY V) for MiroSot [6].

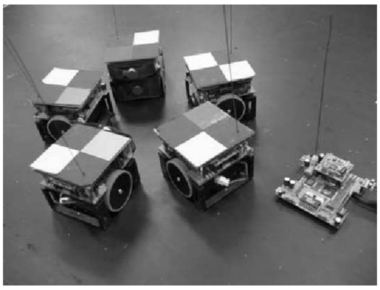


Figure 11: Five robots communicate by CSMA/CD-R

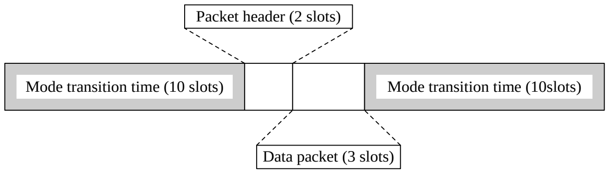


Figure 12: Data format ($T = 25$)

Figure 11 shows the experiment system (SOTY V) for CSMA/CD-R. Five robots (center of the figure) communicate with each other using 424/447MHz frequency and another robot (right of the figure) receive the whole signal to show the status of a channel in the computer.

It takes $2ms$ to change a mode of a commercial communication module, which means 20 slots for transitions (reception to transmission and transmission to reception). Moreover, the packet header of 2 slots (2 bytes) is needed as a packet header for securing the data packet against the possible incoming noise. After that, the data packet of 3 slots (3 bytes) is transmitted as shown in Figure 12.

Experiment results using soccer robots are shown in Figure 13, which are similar to the numerical analysis and simulation results. However, in real experiments, it takes more time for a robot to change its communication mode, accordingly, which makes poorer results than the numerical analy-

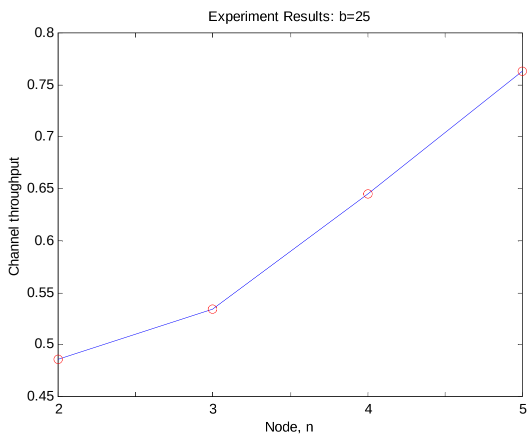


Figure 13: Communication experiment results ($T = 25$)

sis and simulation results.

5. SUMMARY AND CONCLUSION

In this paper, a medium access protocol CSMA/CD-R which was designed for wireless network mobile robots under a distributed robot system (without a centralized mechanism) was proposed. There were several merits in CSMA/CD-R communication protocol as listed below.

- This CSMA/CD-R communication protocol was suited for a distributed robot system, because there was no external and central device. It meant that a robustness which was a major merit of a distributed robot system, could be maintained.
- In the view of scalability, a specific number or any way for identification was not used when each node used a communication channel. Any node could use a communication channel at anytime and robots could be added and extracted without any bad influence for a total robot system. Theoretically, there was no limit to scalability.
- An existing wireline centralized communication protocol, CSMA/CD was modified for a wireless communication protocol for a distributed robot system.
- After a collision, each node could retransmit its signal by a priority (First In First Out), so the performance of CSMA/CD-R protocol was superior to that of CSMA/CD.
- Because a CSMA/CD-R was a asynchronous protocol, the synchronization was not necessary.

CSMA/CD and CSMA/CD-R were compared through various simulations. Simulation results show that CSMA/CD-R has a superiority in the scalability aspect. However, CSMA/CD protocol was more effective in small-size system. This come from a fixed time in CSMA/CD-R, $T-T_{c0}$ for which a node should wait its turn. However, CSMA/CD could not guarantee the priority (fist-in-first-out) and scalability.

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