A Communication Protocol Based on IR-Space Division Transceivers for Mobile Robots

Tetsuo ABE†, Hiroyuki TAKAI†, and Keihachiro TACHIBANA††

† Graduate School of Information Sciences
Hiroshima City University
3-4-1 Ozuka-Higashi, Asa-Minami-Ku, Hiroshima, Japan
Tel: 082-830-1500, Fax: 082-830-1656.
{abe|takai}@sys.info.hiroshima-cu.ac.jp

†† Graduate School of Computer Science
Osaka Gakuin University
2-36-1 Kishibe-Minami, Suita-city, Osaka, Japan
Tel: 06-6381-8434, Fax: 06-6382-4363
tatibana@ogu.ac.jp

Abstract: In this paper, we propose MAC protocols based on our designed Infrared-Space Division Transceiver (IR-SDT) for mobile robots. The IR-SDT has 8 communication modules, so it can communicate with maximally 8 other nodes simultaneously. The number of parallel multiple accesses will be improved by using this transceiver and the protocol specialized for it._In addition, we consider situations in which a packet collision occurs, and propose a protocol that resolves communication-conflictions using signal collision-detection function of IR-SDT. Finally we consider the performance of these protocols, and discuss the influence of signal collision-detection accuracy.

Keywords: mobile robot, MAC protocol, directional communication, SDMA, CDMA/CD on wireless

I. INTRODUCTION

Cooperation by autonomous mobile robots that designed for the purpose of rescue or information collection in disaster areas, exploration in unknown environments has been studied [1][2]. Robots have to exchange information of task progress or report their position each other in order to execute tasks smoothly. Therefore the study about communication networks for mobile robots has been an important theme. Especially over the past decade, this field has become more popular since wireless LAN technology became cheaper.

Broadly divided into 2 specifications as follows are required for communication networks of autonomous mobile robots.

- *Decentralized autonomy*

Autonomous mobile robots have to construct their communication networks by themselves. It is because they basically perform in unknown environments that do not have communication infrastructures. Furthermore, important functions in the system must be decentralized to be fault tolerant.

- *Scalability*

These networks have to keep high performance when the number of robots in the system is large, i.e., in the tens or hundreds. Therefore it is not realistic to prorate limited channels among each robot, like FDM.

These 2 requirements are conflicting, so reconciling them has been a main issue. Using an intensive central station is suitable to manage communications of a lot of robots. However a system that depends on only one station is unreliable.

We proposed a space division transceiver using infrared LEDs and photodiodes up to now in order to realize networks that satisfy these requests. In this paper, we propose a space division MAC protocol specialized for this transceiver. In addition we also look at situations in which signal collision occurs based on the spatial arrangement of robots, and propose a protocol that resolves communication-conflictions. We think we can realize spatially efficient networks using these protocols.

This paper is constructed as follows. In section II, we will give features and issues of several related works, and introduce our designed IR-SDT in section III. In section IV, we will describe the detail of proposed protocols, and mention these performances in section V. Finally we will conclude this paper and mention future work in section VI.

II. RELATED WORKS

Several single channel type-distributed MAC protocols for the wireless communication among mobile robots have been proposed.

1. AR-TDMA [3]

AR-TDMA is a MAC protocol specialized for the cooperative transport by mobile robot team. Robots take the role of leader or follower, and the leader manages the time slot for time-division communication.

In the paper, there is an important premise. If packet collision occurred when the followers are bidding for slot reservation, then the leader will detects the collision by measuring the change in the signal level. However it is difficult since the change in the signal level is related to the distance from a peer on wireless communications. The accuracy of the collision detection is not considered in the simulation of this protocol, but the factor can influence the system performance.

2. CSMA/CD-W [4]

CSMA/CD-W is a random access MAC protocol for communications among robots that provides the function of signal collision-detection on wireless medium, and is based on CSMA/CD. In this protocol, sender nodes sense the carrier state immediately after transmitting to detect simultaneous sending from other nodes. If a sender detects other's simultaneous sending, then it is recognized as a collision, and the sender informs others that. By the scheme, the overhead that caused by a receiver node requesting the retransmission can be reduced when a collision occurs.

However it is the same as CSMA/CD in that senders retransmit after random back-off when collision occurs. Therefore performance will drop when the number of robots in the system increases.

III. OUR PREVIOUS WORKS

The spatial efficiency of wireless communication will improve by using infrared rays that have strong directionality as the carrier, instead of radio waves that diffuse every direction. It is reported that the directional antenna can provide approximately 5 times of the number of parallel communication links, compared with omni-directional antenna in wireless mesh networks [5]. We focused on this advantage, and designed Infrared-Space Division Transceiver (IR-SDT) for the communication among mobile robots [6]. The overhead view of IR-SDT is illustrated in Fig.1.

This equipment consists of 8 communication modules that are placed on the board facing outward. Each module has a photodiode that can detect AOA (angle of arrival) of signals, and an infrared LED, so it can receive and transmit infrared rays. In addition, they are separated by physical barriers, so the reception angle of each module is limited to 60 [deg]. Moreover it prevents disruption of links by setting overlapped areas.

Therefore this equipment can receive several signal rays from different angles simultaneously, and also can transmit signals to a particular direction or omni-directionally. However, notice that it cannot simultaneously send and receive since the LED rays that are emitted when transmitting will diffuse, reflect, and interfere with their own receiver. Therefore it is the same as general antenna in that can perform half duplex communications.

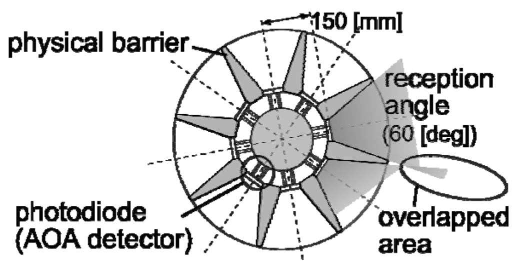

Fig.1. Structure of IR-SDT

Furthermore, the function of AOA detection is important. We use a commercial AOA detecting device (HAMAMATSU, S6560), which outputs the AOA θ as the ratio of electric currents $c\theta$, as shown in Fig.2. By using it, robots can accurately estimate the angle of the peer; and also if 2 or more signal rays enter into a same module, it can be detected as a collision from the fluctuation of the output as shown in Fig.3.

In the next section, protocols that provide the p arallel connection and collision resolution using thes e features will be proposed.

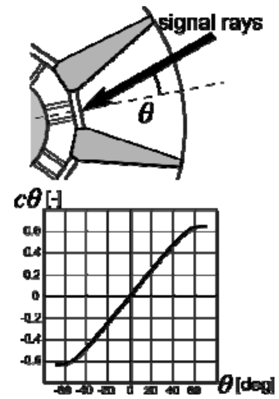

Fig.2. Specification of AOA detector

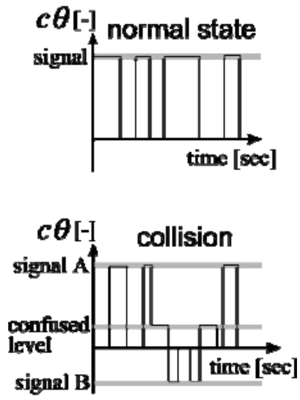

Fig.3. Response for a collision

IV. PROPOSAL

1. Simultaneous Multiple Access Protocol

First, we will describe the protocol for the nodes that make simultaneous multiple access links autonomously in a network. As shown in Fig.4, we implement 4 nodes: S, D, n_1, n_2 on the plane, and they can receive each other's signals. They have unique node-ID, and modules of them IR-SDT also have module-ID. Now node S wants to send message to D, then the steps that follow are executed.

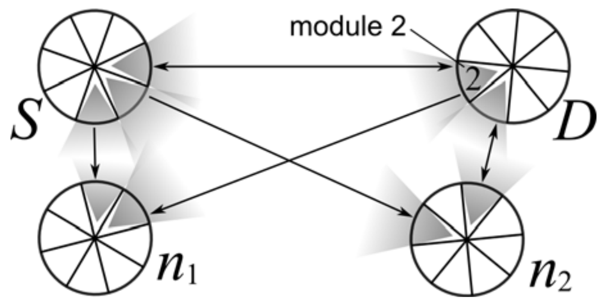

Fig.4. Examples of network

i) S broadcasts a RTS (Request To Send) that specifies the node ID of D. Then it is expressed as "RTS(S, D)" as the RTS from S to D.

ii) n_1 and n_2 wait for constant time $t_{waitCTS}$, and D returns a CTS (Clear To Send) to S. Then that CTS is only transmitted from the module that is used for communication (in this example, module 2), so it is expressed as CTS(D, 2, S) as the CTS from module 5 of D to S.

iii) S receives the CTS and starts to send a message MSG(S, D) to D. Then if other nodes did not receive the CTS, they are allowed to send signals to D; because then they are not facing with module 2 of D. In this case, n_1 is prohibited to send signals to D, but n_2 is allowed to do it. In addition, D returns an ACK (Acknowledgement) with packet-ID to S by receiving constant number *p* of message packets, while receiving the message.

iv) D emits RF (Reception was Finished) from module 2 to release it when receiving the message is finished. Here, it is RF(2).

The sequence chart of above steps is illustrated in Fig.5. By using this method, D can receive messages from other nodes in parallel while ensuring the link for receiving the message from S.

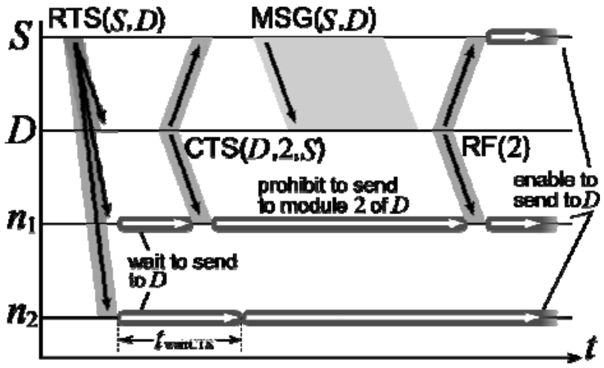

Fig.5. Simultaneous Multiple Access Protocol

2. Collision Detection and Resolution Protocol

In a network consist of IR-SDT, if 2 or more signal rays are received by a same communication module, then these bit patterns are broken and they cannot be decoded. We call this status as collision. Situations that collision occurs can be existed as follow 2 patterns.

A. *Simultaneous RTS broadcasting*
2 or more nodes broadcast RTS at the same time, and they are received by a same module of some node

B. *Interruption by a node that did not listen to RTS/CTS*
While S is sending a message to D, a node that did not listen to RTS/CTS among node S and D moves near D and broadcasts a RTS, and the RTS is received by busy module of D.

We will describe a protocol that detects such collisions and retransmit signals smoothly. For example, we use a network consists of 3 nodes: S_1, S_2 and D on the plane, as shown in Fig.6.

Then we consider situation A and explain an countermeasure for it. The sequence chart of the scheme is illustrated in Fig.7.

A-i) S_1 and S_2 broadcast RTS at the same time. (Then they cannot listen to each other's RTS, since IR-SDT communication is half duplex.)

A-ii) These RTS are received by module 5 of D and collide. D detects the collision, and transmits Collision Notification (CN) from module 5. This CN contains the node-ID, module-ID and the status information when collision occurs. In this example, node-ID is D, module-ID is 5 and status is idling, so the packet is expressed as CN(D, 5, IDLE).

A-iii) S_1 and S_2 receive the CN. In this example, S_1 wants to send a message to D, so S_1 waits a random time and retransmits a RTS only to D. Instead, S_2 wants to send a message to other node, so S_2 waits a constant time for a CTS from desired node. After that, if the CTS is not received, S_2 broadcasts a RTS again, except to the direction of D.

By using this method, conditions in which random back off is inserted can be significantly reduced.

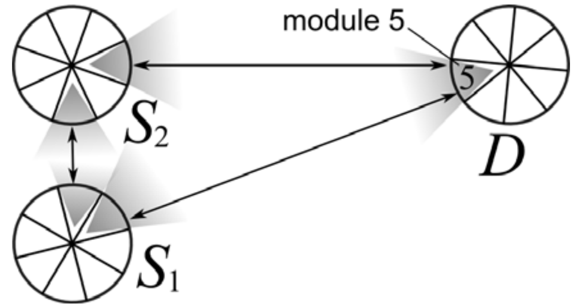

Fig.6. Examples of network

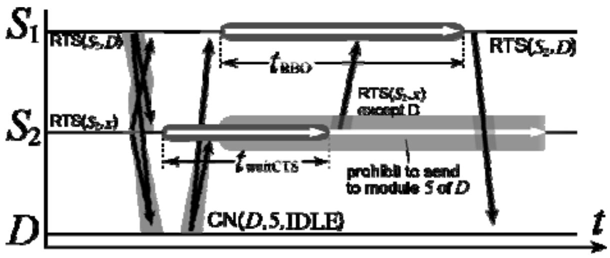

Fig.7. Collision Detection and Resolution Protocol in situation A

Next, let us consider situation B and give a response procedure. Its sequence chart is illustrated in Fig.8.

B-i) When S_1 is sending a message to D, S_2 that could not listen to signals from S_1 or D approaches them, and broadcasts a RTS.

B-ii) The RTS is received by module 5 of D and collide with the message from S_1. Then D transmits CN. This CN is expressed as CN(D, 5, BUSY) because D is receiving a message from S_1.

B-iii) S_2 receives the CN, then if S_2 wants to send a message to D, waits until module 5 of D is released.

B-iv) S_1 retransmits message packets that were not sent successfully.

Owing to this method, S_2 can immediately notice that its own signal was caused by collision.

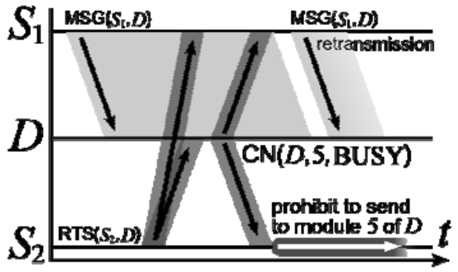

Fig.8. Collision Detection and Resolution Protocol in situation B

V. ABOUT PERFORMANCES

In this section, we discuss about performances of above proposed protocols.

1. Simultaneous Multiple Access Protocol

By the method, every communication module of IR-SDT is used independently, so the maximum number of simultaneous connection links can be 8. However, it cannot reasonably be assumed that all adjacent nodes are at the position where interference does not occur, so the effective value is considered to be lower than it.

In addition, if the time period t_{waitCTS} that waiting for transmission until CTS is too short, then a collision can occur. Instead, if it is too long, it can be an overhead. Therefore we have to investigate the optimal value of the parameter.

2. Collision Detection and Resolution Protocol

About the method, we first consider situations that collisions occur.

Situation A can occur in a network based on CSMA/CA using omni-directional antenna, and the probability can be also considered equal to that. However, diffusion area of signals is limited after step A-3, so nodes can retransmit signals with a low collision probability.

In contrast, situation B only can occur in directional communications, because S_2 refrains from transmission in the environment using omni-directional antenna since then S_2 can listen to messages from S_1. However in directional communications, S_2 refrains from transmission if it received an ACK from D. Therefore the probability depends on the frequency of ACK $1/p$ and the velocity of robots. Thus we also have to set the parameter p to the optimal value.

Moreover, we will discuss about the function of signal collision detection of IR-SDT. If incident angles of collided signal rays are very close, then the fluctuation of the AOA detector's output is small, so it cannot be recognized as a collision. Then the Collision Detection and Resolution Protocol does not work. Therefore the minimum difference of incident angles θ_{lim} that allows a collision to be detected is an important constant for the system.

VI. CONCLUSION

In this paper, we proposed a communication-equipment and MAC protocols based on it for autonomous mobile robots, and discussed about their performances. We will quantitatively evaluate them by numerical simulations to confirm their efficiency. In addition, we have to derive analytically optimal values of parameters as previously mentioned. Furthermore the critical value of incident angle's difference θ_{lim} is also should be obtained by actual experiments.

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