Fusion Center Controlled Carrier Sense Multiple Access for Physical Wireless Parameter Conversion Sensor Networks

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Abstract—**In this paper, a novel fusion center controlled media access control (MAC) protocol for physical wireless parameter conversion sensor networks (PHY-C SN) is proposed. In PHY-C SN, the sensing information is converted to correspond subcarrier numbers of orthogonal frequency division multiplexing (OFDM) signals and sensor nodes can send sensing information simultaneously. Conventionally, each sensor node performs carrier sense for detecting surrounding wireless signal. However, in order to avoid the complexity of a sensor device and to achieve simultaneous transmission from multiple sensor nodes, only the fusion center performs the carrier sense in the proposed protocol. In the proposed protocol, the fusion center detects the surrounding wireless environment and requests sensing information transmission to sensor nodes if no other wireless systems are detected. The transmission power of each sensor is designed not to give harmful interference toward surrounding wireless systems even if each sensor does not have carrier sense function. Finally each sensor node receiving the requested signal simultaneously sends sensing information to a fusion center at the same time. The effectiveness of the proposed protocol is evaluated by computer simulation and confirm the reliable and highly efficient sensing information collection performance.**

I. INTRODUCTION

In recent years, the demand for wireless communications increases further, and is indispensable for the life of every day. Moreover, the sensor network is paid to attention for the establishment of the ubiquitous society that aims at "The network environment anybody accesses anytime and anywhere." The sensor network is to utilize information collection by surrounding sensor nodes. The examples of kind of collecting information are about agriculture, medical treatment, environmental monitoring, and crime prevention and so on. Home automation to which surrounding device are controlled by sensor nodes arranged in home is studied. Smart grid that understands the usage condition of the electric power and adjusts the demand supply are also researched to application [1]. Moreover, the wireless body area network where the information is collected for medical by attaching the sensor node in the body is advanced the research [2]-[3].

There are two kinds of sensor networks, cable and wireless case. The usage of wireless sensor network has increased because of reductions in cost and easiness of construction of network. However, the life issue with wireless sensor nodes exists because the recharge is difficult in a wireless sensor network [4]-[5].

In information collection on the wireless sensor network, the communication using the packet conversion method is chiefly used. This is the method that observation information is subdivided to packet for transmitting. Not only observation information but also the header is contained in the packet, which includes information for destination address and mistake detection. Attaching header makes transmission accurate but it makes volume of date larger.

When the receiver receives multiple packets at the same time, interference occurs at the receiver and the throughput decreases. In order to avoid this interference, carrier sense multiple access with collision avoidance (CSMA/CA) method, whose media access control (MAC) protocol is applied. In CSMA/CA, each sensor node judges whether surrounding systems (including sensor nodes) is active by checking the values of the received power from other surrounding systems when the received power is stronger than threshold (this method is called "carrier sense"). Against, they transmit sequentially across random back-off time. However, the more there are sensor nodes, the more time to collect are needed. Therefore, real-time of information are deteriorated.

To make information collecting faster even if there are many sensor nodes, physical wireless parameter conversion sensor networks (PHY-C SN) have been studied [6]-[8]. Physical wireless parameter conversion is the method that observation information is converted to the orthogonal frequency division multiplexing (OFDM) subcarrier number that corresponds respectively. Information can be transmitted simultaneously because of orthogonality of subcarrier. IDs of sensor nodes (positional data) can be converted to time slots if the individual sensing data are required to be separated. However, in this paper, the faster information collection by transmitting simultaneously without using the time domain is considered. Therefore, PHY-C SN is appropriate when we would like to obtain the real time performance compared with the accuracy of data. In this case, the distribution of the sensing data can be collected. For example, medical equipment, human body and positional detection and so on. At fusion center of receiver side, if the received signal power is more than a certain threshold, a

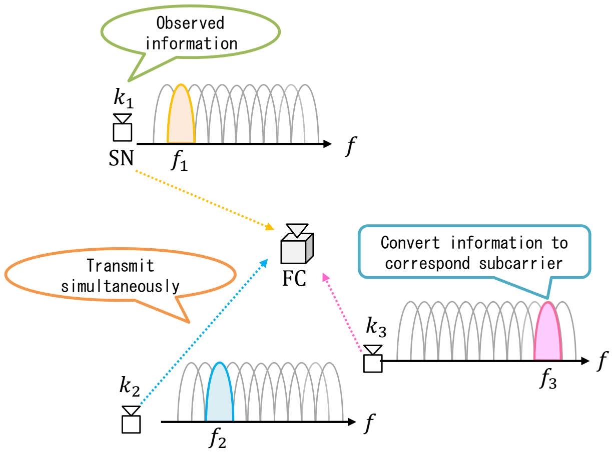

Fig. 1 Information collection by using PHY-C SN.

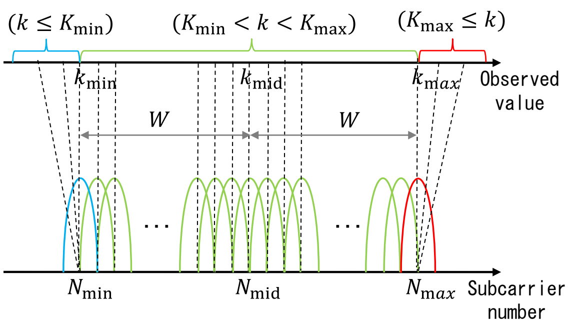

Fig. 2 Converting observed information to subcarrier number.

signal is judged transmitted from sensor nodes after each subcarrier is separated by FFT, and the inverse transform is done from the subcarrier to observation information. Even if the same observed value k is received from two or more sensor nodes, it becomes only 0 or 1 as count. However, it is possible for sensor nodes to convert the observed information to not only correspond subcarrier but also the adjoining subcarrier to avoid the situation in which fusion center receives same subcarriers and the number of observed information that fusion center can detect reduces. As the result, fusion center could detect more information about k and value close to k. However, there is some possibility that signals from surrounding systems are misdetected as observation information when wireless systems using same bandwidth exist around. It is necessary to consider a communication procedure by media access control (MAC) protocol to avoid such misdetection. However CSMA/CA protocol is unsuitable for information collection in PHY-C SN whose advantage is simultaneous collection because each sensor node cannot transmit simultaneously by detecting signal from other sensor node in CSMA/CA.

In this paper, the protocol suitable for PHY-C SN is proposed. In the proposed protocol, the sensor nodes do not perform carrier sense and the fusion center judges whether surrounding systems communicate or not by carrier sense. If no wireless system is detected by carrier sense at the fusion center, the fusion center transmits the request signal to sensor nodes. Each sensor node receiving the request signal transmits an OFDM subcarrier converted from observation information at the same time to the fusion center. This protocol can avoid the interference from other systems by carrier sense at the fusion center and can collect the sensing information from multiple sensor nodes simultaneously. The interference toward other wireless systems can be avoided by designing the transmit power of each sensor node before collecting sensing information. Finally the authors evaluate the number of sensing information collection by using the proposed and the conventional protocols. We also evaluate the calculated sensing information collection area and the number of sensor nodes when the transmit power is limited not to give the interference toward the other wireless system.

II. Physical Wireless Parameter Conversion

Physical wireless parameter conversion method can collect the sensing information faster and easier than packet communication utilized in current standardized wireless sensor networks [6]-[8]. In this paper, the observed sensing information is converted to subcarrier number without considering transmitting sensor ID. Figure 1 shows the process of information collection by using PHY-C SN. First, each sensor node converts observed value to subcarrier number, and simultaneously sends the selected subcarrier signal to the fusion center. On the other hand, the fusion center separates the received signal into subcarriers by FFT and detects subcarriers which have the signal power more than the threshold. Then the signals are inversely converted to the observed sensing value.

The conversion from the observed sensing value to the subcarrier number is shown in Figure 2. The equations of conversion are given by,

$$n(k) = \frac{1}{A}(W + k - K_{\mathrm{mid}}). \quad (1)$$

$$k = (n(k)A + K_{\mathrm{mid}} - W). \quad (2)$$

where $n(k)$ denotes the subcarrier number, k means the estimated observed value transmitted by sensor nodes. $[K_{\mathrm{mid}}, K_{\max}]$ denote the range of observed value k. $[N_{\mathrm{mid}}, N_{\max}]$ and $2W$ denote the range and width of subcarrier number $n(k)$, respectively. By using equations (1) and (2), the faster and the easier information collection than packet communication can be achieved.

III. Interference in Wireless Sensor Network

In current packet communication based wireless sensor networks, those interference are eliminated by applying CSMA/CA. The process of CSMA/CA is shown in Figure 3. Each sensor node detects surrounding wireless signal and transmits the signal among wireless terminals separately to avoid the interference. Surrounding wireless transmitters and

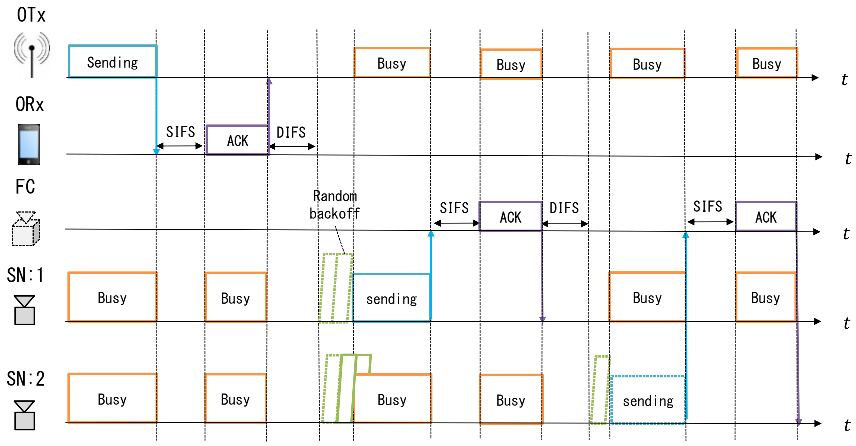

Fig. 3 Processing flow of CSMA/CA.

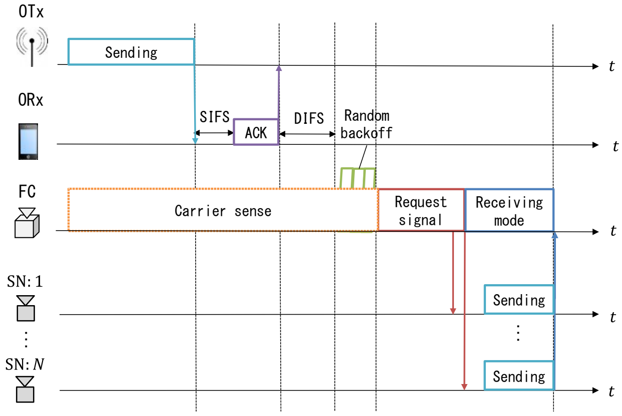

Fig. 4 Processing flow of the proposed protocol.

receivers which use the same frequency band of sensor nodes are denoted as OTx and ORx, respectively.

In PHY-C SN, Fusion center must not receive the interference from OTx because the fusion center estimates the observed sensing information transmitted from sensor nodes by using the received power of each subcarrier element of FFT. The fusion center may misdetect the signals from OTx as signals from sensor nodes. In CSMA/CA, while it is possible for sensor nodes and OTx to transmit signals separately, it is difficult to be simultaneously transmitted from multiple sensor nodes by using PHY-C SN. Therefore, the advantage of simultaneous transmission by using PHC-SN is disappeared. In the studies of [6]-[8], the interference from surrounding system has not been considered and the suitable protocol for collection in PHY-C SN has not been examined yet.

IV. A Novel MAC Protocol for PHY-C SN

In this paper, a novel MAC protocol for PHY-C SN with avoiding interference with surrounding wireless systems and realizing simultaneous sensing information transmission from multiple sensor nodes is proposed. In CSMA/CA, each sensor node detects surrounding wireless systems by carrier sense.

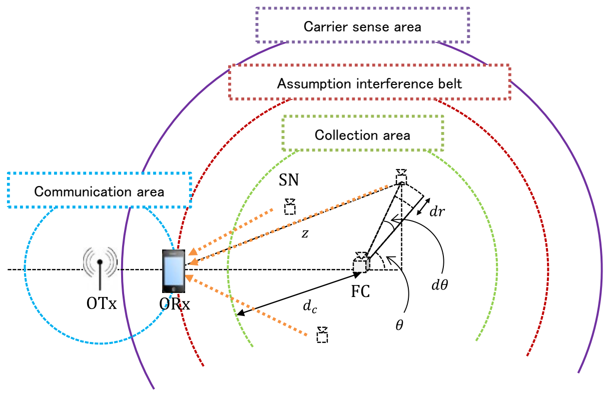

Fig. 5 Transmission power design model.

However in the proposed protocol, the fusion center instead of sensor nodes performs carrier sense and judges whether wireless surrounding systems are active or not. From Figure 4, the fusion center is waiting while OTx is active for transmitting data. After the transmission is finished and random backoff time is passed, the fusion center transmits request signal to sensor nodes and become receiving mode. When the sensor node receives the request signal, it simultaneously transmits observed information by correspond subcarrier number with other sensor nodes. Then, the fusion center converts the received signal into each subcarrier signal element by FFT. The fusion center detects each subcarrier element by comparing the received power level with the threshold and the detected subcarrier number is inversely converted to the observed sensing information. It is not necessary for strict time synchronization because the tone signal of transmitted in each subcarrier is continuous signal. The orthogonality among subcarriers are not destroyed if the continuous signal is input to FFT. Only the frequency synchronization function has to be implemented. In the proposed protocol, since each sensor node only transmits a single tone signal after receiving the request signal from the fusion center, the complexity of each sensor node is smaller than the transmitter used in CSMA/CA.

V. Designing Transmission Power of Sensor Nodes

In this section, a design of transmit power limitation of each sensor node for avoiding giving interference toward surrounding wireless systems is explained. Figure 5 shows a transmit power design model. Here we assume maximum interference situation at ORx. The fusion center can recognize OTx transmission signal when OTx is located within the carrier sense area. Therefore, if we consider worst case scenario, OTx is located on the boundary of the carrier sense area and ORx is located at maximum distance of communication along with the straight line connected OTx with the fusion center. The maximum distance of communication is the distance which satisfies a certain SINR at ORx.

Here, we explain the design of the transmit power limitation by using equations. The transmission power of each sensor node is designed by considering aggregated interference from multiple sensor nodes. The desired received power P_{rFC} of the fusion center per subcarrier is given by,

$$SNR_{FC}=10\log\frac{P_{rFC}}{N\times\frac{W_{SN}}{W_{OT}}\times\frac{2}{SC+1}}. \tag{3}$$

where W_{OT} and W_{SN} is the bandwidth of OTx and the bandwidth of sensor nodes, respectively, N means noise power per W_{OT}, SC means the number of subcarriers.

The Aggregation interference power I_{agg} from sensor nodes to ORx is given by,

$$I_{agg}=\int_0^{2\pi}\int_0^{d_c}P_{tSN}\rho_{SN}r\left(\frac{\lambda}{4\pi d_o}\right)^2\left(\frac{d_0}{z}\right)^n dr d\theta\,. \tag{4}$$

where d_c means the radius of collection area, ρ_{SN} is the density of sensor nodes, λ means the wave length, z denotes the distance of sensor node and ORx.

Moreover, the transmission power P_{tSN} of each sensor node is given by,

TABLE I
SIMULATION PARAMETER I

Name	Value
All bandwidth of sensor nodes	2MHz
Number of subcarriers	512
Request signal	100us
Packet occurrence of OTx	1000us per one time (Poisson distribution)
Data rate of OTx	11Mbps
Payload-length of OTx	800byte
Data rate of sensor nodes (CSMA/CA)	11Mbps
Payload-length of sensor nodes (CSMA/CA)	10byte
Execution time	200000us

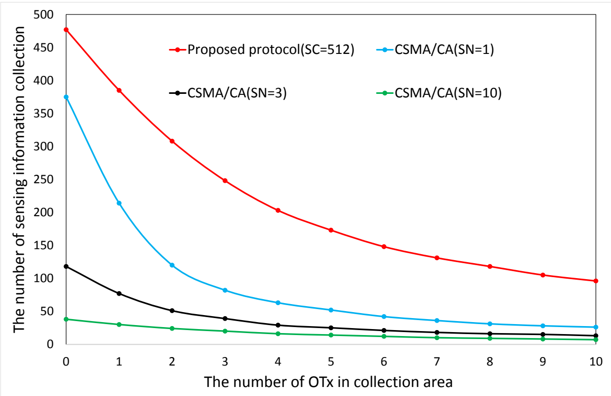

Fig. 6 The number of sensing information collection

$$P_{tSN}(r)=P_{rFC}\left(\frac{4\pi d_0}{\lambda}\right)^2\left(\frac{r}{d_0}\right)^n. \tag{5}$$

Here, P_{tSN} is designed not to exceed the permissible value.

VI. Simulation Evaluation

In this section, we compare the performance between the proposed protocol and the conventional protocol based on CSMA/CA by computer simulation.

A. Information collection performance

At first, we evaluate the number of collected sensing information by using the proposed protocol and the conventional CSMA/CA when the number of OTx is changed. The number of collection is counted if information from all sensor nodes in the collection area are completely collected. The values of SIFS (Short Inter Frame Space), DIFS (Distributed coordination function IFS), ACK (Acknowledgement) and contention window is referred from the standard of 802.11b. The simulation parameter is in Table I.

TABLE II
SIMULATION PARAMETER II

Name	Value
Frequency	2.4GHz
Bandwidth of OTx	20MHz
All bandwidth of sensor nodes	2MHz
Number of subcarriers	512
Noise power per ORx	-95dBm
Reference distance	1.0m
Transmission power of OTx	10dBm
Permissible interference power	-100dBm
Desired SINR of ORx	25dB
Desired SNR of fusion center	30dB
Coefficient of distance delay	3.0

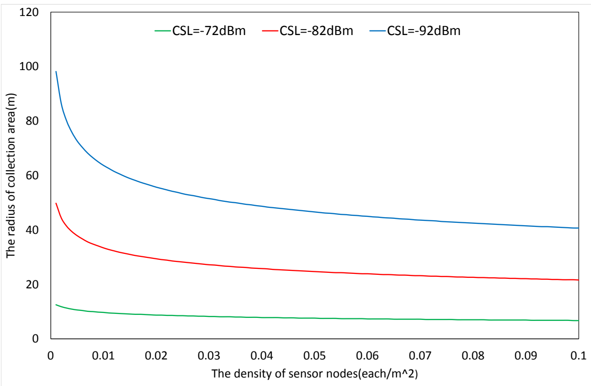

Fig. 7 The radius of collection area

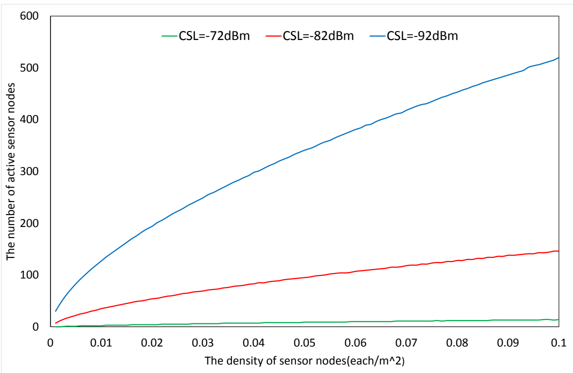

Fig. 8 The number of active sensor nodes

Here, it is assumed that there is no hidden terminals because the method for avoiding influence coming from relationship between carrier sensing level and P_{rFC} have not been considered yet. If carrier sense level is more than P_{rFC}, there are hidden terminals because the fusion center detects signals from OTx as signals from sensor nodes when the received power of the signals exceeds P_{rFC} and it does not exceed carrier sense level. On the other hand, if P_{rFC} is more than carrier sense level, There are none hidden terminals. However, the collection area and the number of sensor nodes to collect information reduces because the more sensing level sets, the higher transmission power is required. The method to cope with this problem must be consider for future work.

Bandwidth W_{sub} per a subcarrier is

$$W_{sub} = \frac{W_{SN} \times 2}{SC+1}. \quad (6)$$

Therefore, the transmission time of each sensor node in the proposed protocol is given by

$$T = \frac{SC+1}{W_{SN} \times 2}. \quad (7)$$

Figure 6 shows the result of the number of sensing information collection. The performance of the proposed protocol achieve the best compared with CSMA with different number of sensor nodes. Since multiple sensor nodes simultaneously transmit the sensing information by using the proposed protocol, the performance is the same even if the number of sensor nodes is different. The points in which the proposed protocol are superior to CSMA/CA even if the number of sensor node is 1 are removing the header, SIFS and ACK in the proposed protocol. In CSMA/CA, if the number of sensor nodes increases, the more time is needed to completely collect the sensing information from all sensor nodes. On the other hand, multiple sensor nodes can transmit at the same time in the proposed protocol. Therefore, more effective collection is realized with avoiding interference from surrounding wireless systems.

B. *Performance impact by limiting transmission power*

Here, the radius of the collection area and the number of sensor nodes when the designed transmission power of each sensor node is applied. The number of sensor nodes is computed by the product of density of sensor nodes and collection area. The density of sensor nodes ranges [0.001, 0.1]. The simulation parameter is in Table II. The results of simulations are shown in Figs. 7 and 8. From these results, the radius of collection area decreases and the number of sensor nodes increases according to increasing the density of sensor nodes. In addition, the less carrier sense level is taken, the more collection area and number of sensor nodes can be achieved. However, to reduce the carrier sense level makes more surrounding systems recognized by carrier sense and more time needed to collect for avoiding interference. From these results, it is necessary to adjust the carrier sense level properly according to the environments that collect sensing information.

VII. CONCLUSION

In this paper, a novel protocol for PHY-C SN is proposed. In this protocol, only fusion center performs carrier sense and sending request signal to sensor nodes. By using the proposed protocol, simultaneous sensing information collection is realized with avoiding interference from surrounding systems. The more effective information collection could be confirmed in the proposed protocol than CSMA/CA by simulation. Moreover, the interference to surrounding wireless systems is suppressed by designing transmission power according to the demand of the fusion center before starting transmission. By using computer simulation, we confirm the proposed protocol achieves highly efficient information collection that avoids mutual interference with surrounding wireless systems. However, there is some possibility of occurring interference by hidden terminals because of relationship between the carrier sense level and the desired received power of fusion center. We plan to design more strict interference management for future work.

ACKNOWLEDGEMENT

A Part of this work was supported by the Ministry of Internal affairs and Communications (MIC) of Japan under the 2014 and 2015 SCOPE R&D for Very High Efficient Wireless Sensor Networks with Environment Recognition.

REFERENCES

[1] Vehbi C. Güngör, D.Sahin, T.Kocak, S.Ergüt, C.Buccella, C.Cecati, Gerhard P.Hancke, “Smart grid technologies: communication technologies and standards,” IEEE Transactions on Industrial Informatics, vol.7, no.4, pp.529-539, Nov. 2011.
[2] S.Ivanov, D.Botvich, S.Balasubramaniam,”Cooperative wireless sensor environments supporting body area networks,” IEEE Transactions on Consumer Electronics, vol.58,no.2 pp.284-292, May 2012.
[3] K.Kim, Ick-Soo Lee, M.Yoon, J. Kim, H.Lee, K.Han,” An efficient routing protocol based on position information in mobile wireless body area sensor networks,” First International Conference on Networks & Communications, pp.396-399 2009.
[4] W.Ye, J.Heidemann, D.Estrin,“An energy-efficient MAC protocol for wireless sensor networks,” Proceedings of the IEEE INFOCOM, pp.1567-1576, 2002.
[5] W.Zhao, X.Tang,” Scheduling sensor data collection with dynamic traffic patterns,” IEEE Transactions on Parallel and Distributed Systems, vol.24, no.4 pp.789-801 April 2013.
[6] T.Endo, T.Fujii, “Real time information gathering based on frequency and timing assignment for wireless sensor networks,” ICCS2012, Nov. 2012.
[7] S.Sakai, T.Endo, T.Fujii, “Frequency assigned information gathering method for motioncapture in wireless sensor networks,” ICUFN2013, July. 2013.
[8] S.Sakai, T.Fujii, "Performance of physical wireless parameter conversion sensor network (PHY-C SN) using frequency hopping," Network Infrastructure and Digital Content (IC-NIDC), Sept. 2014