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Power Saving Effect of Sensor Collaborative Beamforming for Wireless Ubiquitous Network Systems

Sousuke Tokunaga†, Yoshihisa Kawakami††, Kenichi Hashimoto†,
Shigeru Tomisato†, Satoshi Denno†††, and Masaharu Hata†,
†Graduate School of Natural Science and Technology, Okayama University
††Faculty of Engineering, Okayama University
3-1-1, Tsushima-Naka, Okayama, 700-8530, Japan
Tel: +81-86-251-8269; Fax: +81-86-251-8124; E-mail: tokunaga@mob.cne.okayama-u.ac.jp
†††Graduate School of Informatics, Kyoto University
Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan
Tel: +81-75-753-5789; Fax: +81-75-753-5349

Abstract-**This paper evaluates transmission performance and power-saving effect of the collaborative beamforming for wireless ubiquitous network systems. The evaluation of power-saving includes the power consumption for signal transmission to collaborative sensors in beamforming. The simulation result shows that the total power consumption of the beamforming with 3 collaborative sensors can be decreased to about 1/2 compared with that of a transmitting sensor without the beamforming in free-space propagation channels. In typical mobile propagation channels with shadowing, the total power consumption of the beamforming by using 3 collaborative sensors can be reduced to 1/7 of that without the beamforming. The above results confirm that the collaborative beamforming can be achieve lower power consumption, and greatly contributes to realize low-power transmission in wireless sensor network systems.**

Keywords: Sensor Network, Transmit Beamforming, Sensor Collaboration

I. INTRODUCTION

Wireless sensor network technology is very effective in realizing future ubiquitous network systems [1][2]. Wireless sensor networks consist of low-cost sensors with reduced size and power unlike conventional wireless communication networks. Because the transmitting antenna of each sensor is small and its transmitting power is low, it is very difficult to realize highly reliable transmission. In multi-hop wireless networks, transmission performance remarkably degrades when the distance between two transmission sensors is especially long.

Transmission performance of collaborative beamforming among several transmitting sensors, which can achieve high-reliability transmission in wireless sensor networks, has been evaluated [3–5]. This collaborative beamforming is very effective in the improvement of transmission performance, and can obtain power-saving effect. However, the beamforming needs a lot of power to transmit information signals from a transmitting sensor to collaborative sensors before beamforming.

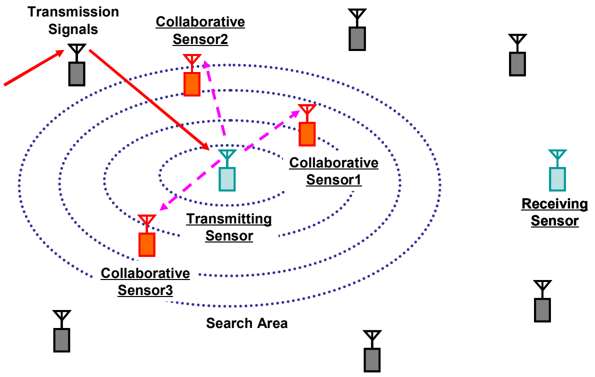
This paper evaluates transmission performance of the collaborative beamforming and power-saving effect including the power consumption of the signal transmission to collaborative sensors. The bit error rate (BER) performance of the collaborative beamforming is calculated by computer simulations, and power-saving effect is estimated by using the calculated BER performance.

First, the collaborative beamforming method for sensor network systems is explained, and then BER performance with the beamforming by computer simulations and power-saving effect are presented.

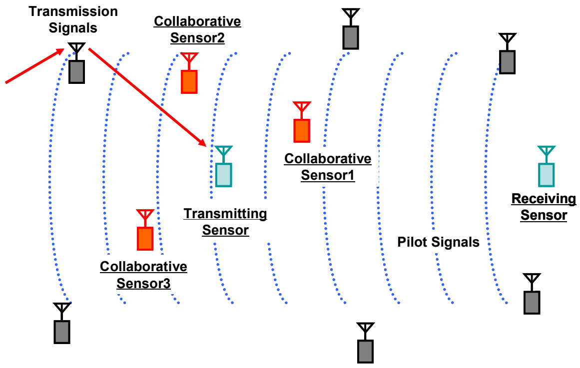
II. COLLABORATIVE BEAMFORMING METHOD

Figure 1 shows the system model and the collaborative beamforming considered in this paper. The system consists of many sensors with wireless transmission units. Each sensor senses surrounding environment, and the sensing results are transmitted by using multi-hop transmission with other sensors.

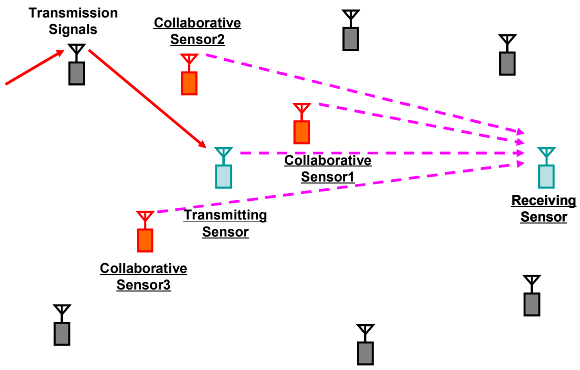
The collaborative beamforming is performed to stabilize received power in wireless propagation channels. First, a transmitting sensor searches collaborative sensors within a set distance, and sends transmission signals to the collaborative sensors as shown in Fig.1(a). Figure 1(b) shows pilot signal transmission, in which a receiving sensor outputs pilot signals to transmitting and collaborative sensors in order to inform them of their receiving phases. Figure 1(c) shows that the transmitting and collaborative sensors reverse their received phases of pilot signals, respectively, and send transmission signals with their reversed phases to realize in-phase combining at a receiving sensor.



(a) Collaborative sensor search



(b) Pilot signal transmission



(c) Signal transmission

Fig.1 System model and collaborative beamforming.

III. Consumption Calculation Power

In this paper, the power-saving effect in the collaborative beamforming is represented by using the value of transmitting power reduction compare with the transmitting power without beamforming. Propagation models are assumed to be free-space channels from a transmitting sensor to collaborative sensors, and free-space and mobile radio channels are assumed from transmitting and collaborative sensors to a receiving sensor. The total transmitting power of the collaborative beamforming, P_B, is

$$P_B = P_1 + P_2 \qquad (1)$$

where P_1 is the transmitting power from a transmitting sensor to collaborative sensors and P_2 is the transmitting power from transmitting and collaborative sensors to a receiving sensor.

When the free-space channel model is assumed in both propagation channels, the total transmitting power P_{Bf} can be represented as

$$\begin{aligned} P_{Bf} &= P_{1f} + P_{2f} \\ &= R^{\alpha_f} P_{0f} + \frac{1}{G_{f,R,N_c}} P_{0f} = \left(R^{\alpha_f} + \frac{1}{G_{f,R,N_c}} \right) P_{0f} \end{aligned} \qquad (2)$$

where P_{0f} is the required transmitting power without the beamforming under free-space propagation channels, R is the radius of collaborative sensor search area normalized in the distance between a transmitting sensor and a receiving sensor, α_f is the attenuation factor of free-space channels, and $G_{f,R,Nc}$ is the gain in the transmitting power by using the beamforming which is obtained by R and the collaborative sensor number N_c. The value of $G_{f,R,Nc}$ is calculated by the following computer simulations for BER performance.

The total power in mobile radio propagation channels P_{Bm} is given by

$$\begin{aligned} P_{Bm} &= P_{1m} + P_{2m} \\ &= \frac{R^{\alpha_f}}{A_m} P_{0m} + \frac{1}{G_{m,R,N_c}} P_{0m} = \left(\frac{R^{\alpha_f}}{A_m} + \frac{1}{G_{m,R,N_c}} \right) P_{0m} \end{aligned} \qquad (3)$$

where P_{0m} is the required transmitting power without the beamforming under mobile radio propagation channels, A_m is the transmitting power ratio between free-space propagation and mobile radio propagation channels without beamforming, and $G_{m,R,Nc}$ is the transmitting power gain determined by R and N_c in mobile radio propagation channels. The values of A_m and $G_{m,R,Nc}$ are obtained by the BER performance evaluation of computer simulations.

IV. Simulation Results

A. Simulation Conditions

Computer simulations were conducted to clarify BER performance with collaborative beamforming, and power-saving effect is estimated by using the calculated BER performance. The simulation conditions are shown in Table 1. The modulation scheme was QPSK. The numbers of transmitting and receiving sensors were set to be 1, respectively. The number of collaborative sensors was 1, 3 and 5. The symbol number a frame was 128. The transmitting power of all sensors is equal, and the total power is fixed regardless of the number of collaborative sensor in BER performance evaluation.

TABLE I
SIMULATION CONDITIONS

Modulation	QPSK
Transmitting and Receiving Sensor	1
Collaborative Sensors	1, 3, 5
Symbol Number/Frame	128
Sensor Transmitting Power	Equal

Two propagation models are assumed in the simulations. One is the free-space propagation model in which the attenuation factor α is set to be 2.0, and the other is the mobile radio propagation model in which α is set to be 3.5 and the standard deviation of shadowing is set to be 6.5 dB.

The search area of collaborative sensors is determined by the radius normalized in the distance between transmitting and a receiving sensors. The normalized radius R was set to be 0.0, 0.3, and 0.5. The case of R = 0.0 is equivalent to the transmitting diversity with plural antennas of one sensor.

B. BER Performances

Figure 2 shows BER performances with sensor collaborative beamforming under free-space propagation channels. The number of collaborative sensors, N_c, is 1. The E_b in the horizontal axis of Fig.2 represents the energy per bit. Figure 2 shows that the beamforming with 1 collaborative sensor can improve the required E_b/N_0 by 2.3 dB as compared with that without the beamforming at R = 0.5 and BER = 10^{-3}. This gain of the required E_b/N_0 is used in the calculation of power-saving effect as $G_{f,R,Nc}$.

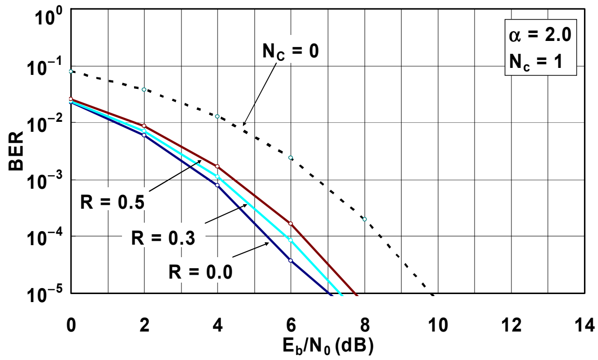


Fig. 2 BER performance under free-space propagation channels (N_c = 1, α = 2.0)

Figure 3 shows the BER performance with 3 collaborative sensors. The result shows that the improvement of the required E_b/N_0 is 5.6 dB by collaborative beamforming at R = 0.5 and BER = 10^{-3}. The value of 5.6 dB is used in the power-saving evaluation with 3 collaborative sensors.

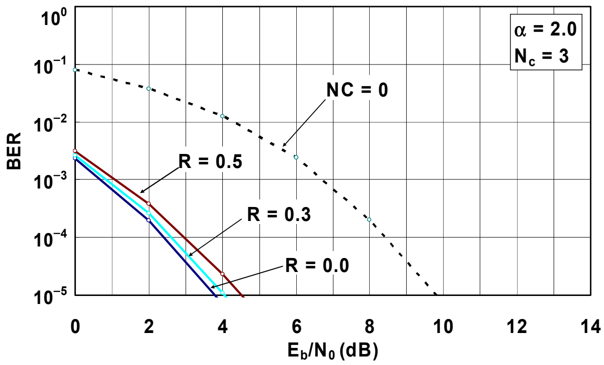


Fig. 3 BER performance under free-space propagation channels (N_c = 3, α = 2.0)

Figure 4 shows the BER performance with 5 collaborative sensors. The result shows that the gain of collaborative beamforming is 7.6 dB.

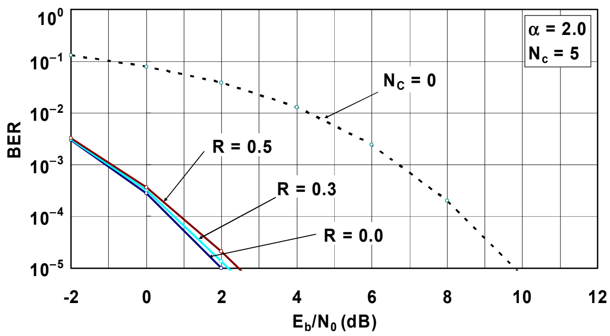


Fig. 4 BER performance under free-space propagation channels (N_c = 5, α = 2.0)

Figure 5 shows BER performances with sensor collaborative beamforming under mobile radio propagation channels with shadowing. The result shows that the beamforming with 1 collaborative sensor can improve the required E_b/N_0 by 4.9 dB at R = 0.5 and BER = 10^{-3}. Because BER performance without beamforming remarkably degrades under the mobile channels, the improvement by beamforming is lager than that under free-space propagation channels. This gain in the required E_b/N_0 is used in the calculation of power-saving effect as $G_{m,R,Nc}$.

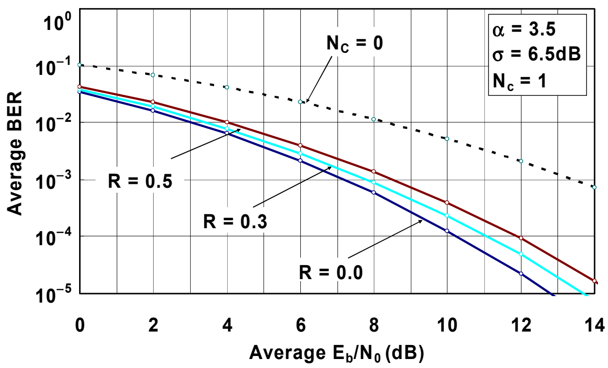


Fig. 5 BER performance under mobile radio propagation channels (N_c = 1, α = 3.5)

Figure 6 shows the BER performance with 3 collaborative sensors. The result shows that the improvement of the required E_b/N_0 is 10.5 dB by collaborative beamforming at $R = 10^{-3}$ and BER = 10^{-3}.

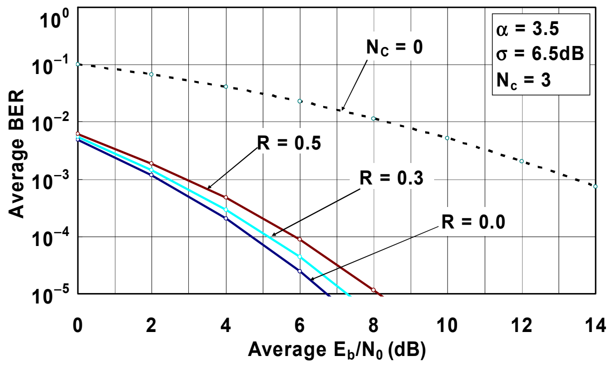


Fig. 6 BER performance under mobile radio propagation channels (N_c = 3, α = 3.5)

Furthermore, the transmit beamforming with 5 collaborative sensors can obtain the required E_b/N_0 improvement by 13.3 dB at R = 0.5 and BER = 10^{-3} as shown in Fig. 7 under mobile radio propagation channels.

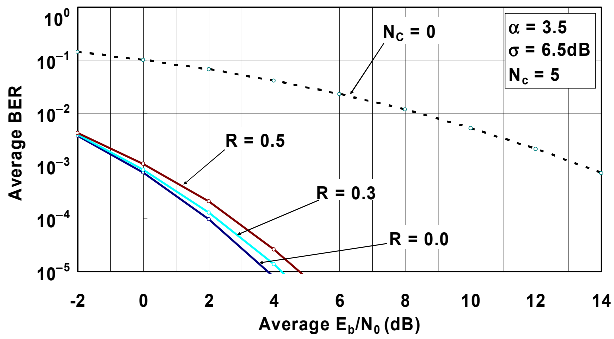


Fig. 7 BER performance under mobile radio propagation channels (N_c = 5, α = 3.5)

C. *Power-Saving Effect*

Figure 8 shows power-saving effect of the collaborative beamforming including the power consumption of the transmission to collaborative sensors under free-space propagation channels. The values of $G_{f,R,Nc}$ were set to be 2.3 dB, 5.6 dB and 7.6 dB at N_c = 1, 3 and 5, respectively. The calculation result of power consumption with collaborative beamforming is normalized by that without the beamforming of P_{0f}.

Figure 8 shows that the total power consumption of the beamforming with 3 collaborative sensors can be reduced to about 1/2 compared with that of a transmitting sensor without the beamforming at R = 0.5.

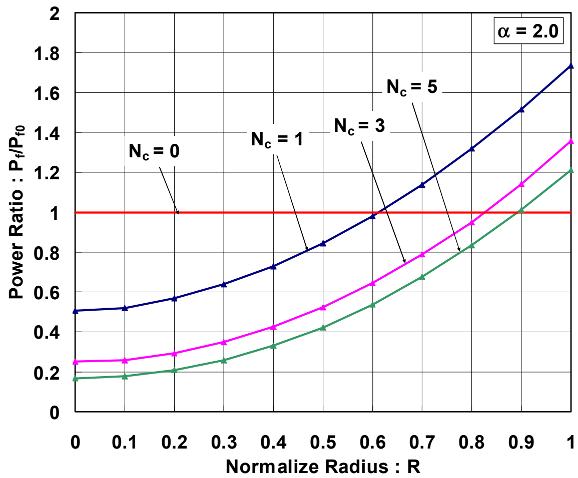


Fig. 8. Power-saving effect under free-space propagation channels (α = 2.0)

Figure 9 shows power-saving effect of the collaborative beamforming under mobile radio propagation channels with shadowing. The values of $G_{m,R,Nc}$ were set to be 4.9 dB, 10.5 dB and 13.3 dB at N_c = 1, 3 and 5, respectively.

In typical mobile propagation channels with shadowing, the total power consumption of the beamforming by using 3 collaborative sensors can significantly be reduced to 1/7 of that without the beamforming at R = 0.5.

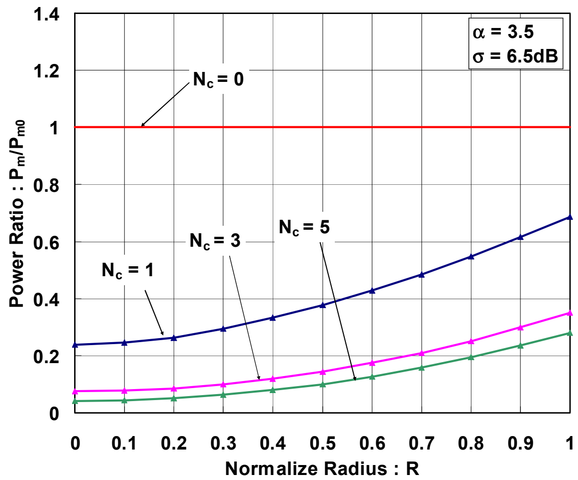


Fig. 9. Power-saving effect under free-space propagation channels (α = 3.5)

V. Conclusion

This paper has evaluated transmission performance of the collaborative beamforming and power-saving effect including the power consumption of information signal transmission to collaborative sensors before beamforming. The results show that the beamforming can reduce power consumption to 1/7. The simulation results confirm that the collaborative beamforming greatly contributes to realize low-power transmission in wireless sensor network systems.

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