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LETTER

Active-time reduction of base stations for energy reduction using estimated terminal position via wireless-communication signals

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Abstract This paper proposes an active-time-reduction technique of base stations for energy reduction using terminal position information estimated from wireless-communication signals. Although high-frequency wireless communication system requires dense deployment of base stations, the system is enabled to detect terminal position from communication signals. The proposed technique was evaluated using a formula car as an example of a high-speed mobility environment. The results indicate the base-station-active time decreased by about 59% without any degradation in transmission performance, suggesting that the proposed technique can reduce power consumption of base stations.

Keywords: millimeter wave, IEEE 802.11ad, positioning, energy reduction
Classification: Wireless communication technologies

1. Introduction

To handle the demand of ultra-large-capacity transmission caused by various types of wireless-communication services, such as extended-reality (xR) devices, the construction of high-frequency wireless communication using millimeter-wave (mmWave) or sub-terahertz bands, which have rich frequency resources, is progressing in the 5th generation (5G) and next-generation wireless-communication systems. Such high-frequency wireless-communication systems are characterized by huge distance attenuation, so dense and overlapped deployment of base stations (BSs) is required to provide persistent wireless-communication service [1, 2]. To support heavy traffic demand and stable connectivity, a heterogeneous network (HetNet) has been considered [3, 4]. To support heavy traffic demand, high-frequency wireless communication, such as millimeter-wave, is used and low-frequency wireless communication, such as the sub-6GHz band, is used to maintain connectivity. HetNet also increases the number of BSs because BSs are needed for each frequency band.

Increasing the number of BSs by dense deployment and HetNet increase power consumption. Therefore, power-consumption-reduction techniques using the sleep control of BSs have been proposed and evaluated [5, 6]. With these techniques, terminal distribution or daily traffic fluctuation are mainly targeted, which can enable overall system optimization. However, it is difficult to support sudden fluctuation in terminal distribution or traffic.

High-frequency wireless-communication systems enable simple terminal-position estimation from wireless-communication signals [7]. If a system can detect the terminal position, more detailed sleep control of BSs is possible. Here, sleep control means switching of the state of the BS, that is, switching of activated and deactivated. Therefore, more detailed sleep control is expected to provide reduction of the BSs active time. We propose an active-time-reduction technique of base stations using terminal-position information estimated from wireless-communication signals. We evaluated our technique using a Formula car as an example of a high-speed mobility environment.

2. Active-time-reduction technique involving estimated terminal position

Terminal position can be used as an indicator of sleep control. If no terminals are expected to be connected to one BS, the BS can be put to sleep to reduce power consumption. As shown in Fig. 1, terminal position is obtained from high-frequency wireless-communication signals [7]. Specifically, high-frequency wireless communication requires beamforming to compensate for large distance attenuation. For insight (direct path) communication, beam direction shows the terminal direction. Rich frequency resources enable high-frequency wireless communication to wide-band frequency allocation (a wider frequency band equals a narrower time sample). Therefore, the resolution of transmission-distance detection using signal round-trip time (RTT) improves. The combination of beam direction and distance detection enables wireless-communication systems to estimate terminal position using only one BS.

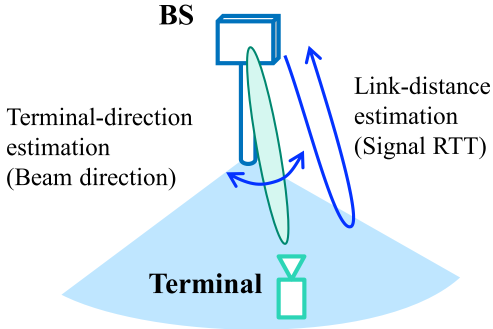

Fig. 1 Positioning based on high-frequency communication signals.

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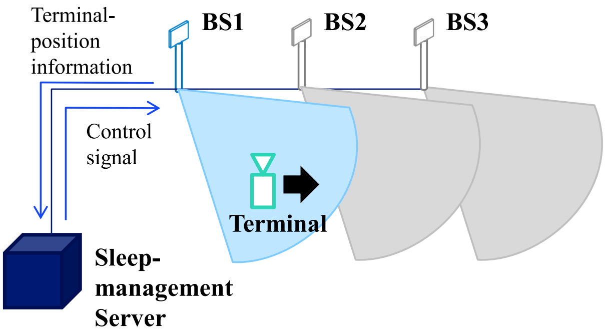
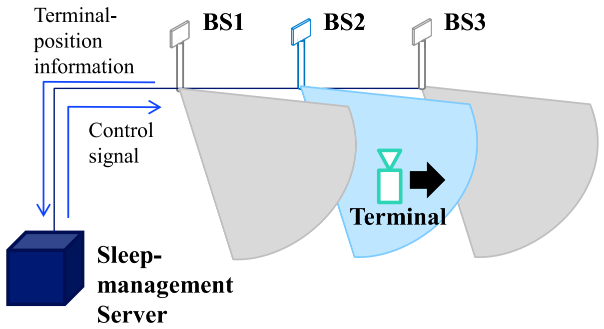


(a) Example of proposed technique (before terminal moves).



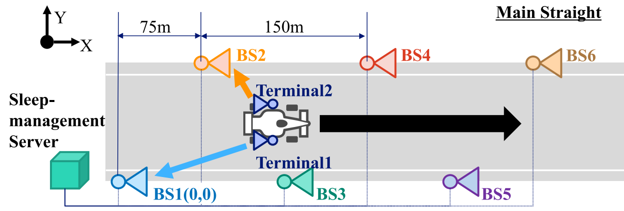
(b) Example of proposed technique (after terminal moves).

Fig. 2 Proposed technique based on terminal position.

Figure 2 (a) is an example of the proposed technique when BS2 and BS3 are deactivated (shown in gray) and BS1 is activated (shown in blue). When the terminal is connected to BS1, terminal-position information detected with the method described above is sent to the sleep-management server. When the server detects the terminal approaching the service area of BS2, the server activates BS2 by sending a control signal. Figure 2 (b) shows an example of when BS2 is activated. A similar procedure is possible for BS3. After the terminal leaves the BS zones, the sleep-management server doesn't detect any other terminals that will connect to BS2 and BS3. Therefore, the server deactivates BS2 and BS3 by sending a control signal. If the BSs are deactivated, BS power consumption can be reduced by stopping wireless signal transmission and other BS circuits. In this procedure, BS1 is always activated to detect terminals. This activated BS should be placed on an edge of the service area to detect approaching terminals.

3. Experiment in high-speed mobility environment

To evaluate the proposed technique, we conducted an experiment using a formula car as an example of a high-speed mobility environment. The experiment was conducted at Suzuka Circuit, Japan on December 8, 2022 at the Joint Test/Rookie Test of the All Japan Super Formula Championship. Figure 3 shows the experimental environment. The 60-GHz wireless LAN was employed as an example of high frequency wireless communication and its service area was configured on the main straight of the circuit. The 6 BSs were put on the course side and connected to the



(a) Schematic of experimental environment.

(b) Terminal and BS antennas.

Fig. 3 Experimental environment.

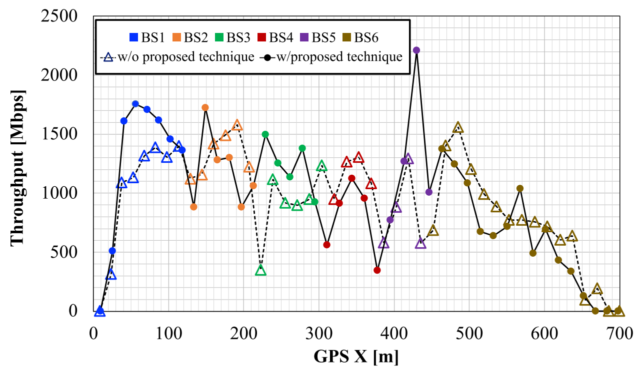
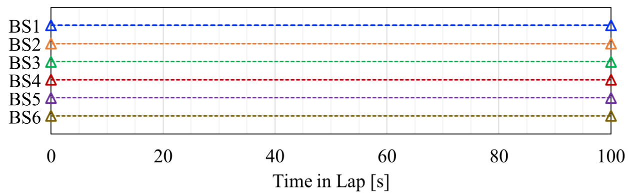


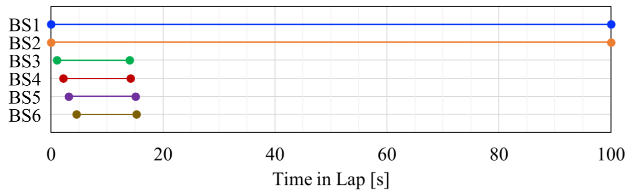
Fig. 4 Measured throughput measured at each BS.

sleep-management server. BS1 and BS2 were always activated to detect terminal position when the car entered the main straight. The states of BS3 to BS6 were managed with the sleep-management server. Each BS was activated when the terminal approached 100 m from it. When no terminals were connected to the BS and adjacent BSs, the sleep-management server waits 2 s just in case of returning of terminal and deactivates the BS. The antenna structure was similar to that described in a previous study [7]. BS sleep was emulated by transmitting and stopping only beacon signals of IEEE 802.11ad [8] device due to device limitations. The handover scheme including seamless handover described in a previous study [7] was also activated.

Figure 4 shows the wireless throughput measured at each BS. The marker color denotes the BS used to receive the test data. The dashed line shows the results without the proposed technique, i.e., no deactivation procedure was executed for all BSs, at a car speed of 248 km/h at X = 0 m and 281 km/h at X = 581 m. The solid line shows the results with the proposed technique, i.e., the BS3 to BS6 states were controlled with the sleep-management server. The car speed was 246 km/h at X = 0 m and 282 km/h at X = 599 m. Due to seamless handover [7], no interruption was observed for both scenarios. High-speed wireless transmission over 300-Mbps transmission was achieved for an area larger than 600 m. The total transmitted data amount was 1031 Mbytes without the



(a) Active time of each BS without the proposed technique



(b) Active time of each BS with the proposed technique

Fig. 5 Active time of each BS.

proposed technique and 1077 Mbytes with it. The results indicate that there was no degradation in throughput performance with the proposed technique.

We then evaluated power consumption in terms of BS-active time. Figure 5 (a) shows the active time of each BS without the proposed technique. This evaluation was conducted per lap. The car ran the lap in 100 s; therefore, the active time was 100 s when the BS was always activated. Figure 5 (b) shows the active time of each BS with the proposed technique. The active time of the controlled BSs (BS3 to BS6) decreased to about 12 s. The total active time decreased from 600 to 247.6 s, and the reduction ratio of active time was about 59%. These results were obtained from only one terminal in the service zone. The reduction ratio will change on the basis of the number of terminals, i.e., it will decrease with increasing number of terminals. However, the maximum active time is equal to that without the proposed technique. Therefore, the proposed technique can reduce the total power consumption of a wireless-communication system with reducing power consumption of densely deployed BSs.

4. Conclusion

We proposed an active-time-reduction technique for energy reduction using terminal-position information estimated from wireless-communication signals. The technique is based on the characteristics of high-frequency wireless communication systems such as beam forming and wide-band transmission. We evaluated the performance of proposed technique using a Formula car as an example of a high-speed mobility environment. The results indicate that the proposed technique can reduce the active time of all BSs by about 59% with no degradation in transmission performance even at car speeds of more than 240 km/h.

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