A low power and high speed data transmission system based on 2D communication

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Abstract: Low power communication systems such as ZigBee enable battery-driven sensor nodes in wireless sensor networks (WSNs). Recent growing demand for transferring large amount of data across a WSN requires more energy-efficient communication schemes. Energy efficiency, evaluated in terms of energy-per-bit rate (EBR), determines the upper bound of information quantity that can be transferred while consuming all the energy stored in a battery embedded in each sensor node. TransferJet is one of the most energy efficient wireless communication schemes. It achieves 2–3 orders of magnitude lower EBR than ZigBee, at the expense of very short communication range up to a few centimeters. In this paper, we report on a preliminary experiment of energy efficient signal transmission using TransferJet devices on two-dimensional communication (2DC) system. It worked at reasonably high transmission rate of 71 Mbps with 1.7-nJ/bit EBR. We also explain the feasibility of a room-scale high-speed communication system with such a low EBR based on 2DC technology.

Keywords: two-dimensional communication, wireless sensor network, Internet of Things (IoT)

Classification: Wireless Communication Technologies

References


1 Introduction

A developing CMOS technology and increasing variety of low power communication systems enable battery-driven sensor nodes in wireless sensor networks (WSNs) and the Internet of Things (IoT). ZigBee and Bluetooth are representative wireless communication standards used in battery-driven WSN. On the other hand, their energy-per-bit rate (EBR), which is the energy required per a single bit transfer, is higher than that of conventional Wi-Fi [1]. EBR determines the maximum amount of information that can be transferred within their battery life. For example, a ZigBee device driven by an AA-sized battery, in which roughly 10,000 J of energy is stored, can transmit at most 1 GB of information [2].

In other words, the EBR and the battery capacity determine the battery life. Suppose a temperature sensing application that operates at 10-Hz sampling-rate with 10-bit resolution of digital to analog converter (DAC). Its data rate, 100 bps, enables 28,000-hours operation of ZigBee transmitter with a 10,000-J AA-battery. A sound sensor, operating at 40-kHz sampling-rate and 10-bit DAC, generates 400-kbps data stream. In this case, the battery life is reduced to only 7 hours. To extend the battery life, the EBR has to be reduced.

At the expense of very short communication range up to a few centimeters, TransferJet [3] can operate at 2–3 orders of magnitude lower EBR than ZigBee. Although its remarkably high energy efficiency is attractive, its very short transmission range is not acceptable in room-scale WSNs.

In this paper, we report on a preliminary experiment of energy efficient signal transmission using TransferJet devices on a two-dimensional communication...
(2DC) system, as a feasibility study of low-EBR room-scale communication system. It achieved a data rate higher than 70 Mbps with an EBR of 1.7 nJ/bit on a 50-cm square 2DC sheet. The EBR is significantly lower than that of ZigBee. We also explain the feasibility of a room-scale communication system at a higher data rate with such a low EBR of the mobile nodes based on 2DC technology. The possibility of 2DC of TransferJet was once demonstrated at CEATEC [4] by a Japanese company, but the sheet size was small and the technical report has not been published yet.

The rest of this paper is organized as follows. In Section 2, our motivation will be described. Section 3 will present a brief review of 2DC tile systems and Section 4 will explain the possibility of energy-efficient signal transmission on 2DC. Experiment will be shown in Section 5. Finally, Section 6 concludes this paper.

2 Low power communication systems

To figure out the motivation of this work, related technologies are compared in Fig. 1, in terms of EBR, transmission rate, and communication range. Those data are based on evaluation of commercially available modules [3, 5, 6]. Related technologies mapped in the figure are: ZigBee, Bluetooth, WiFi (IEEE 802.11b), Passive Wi-Fi [6] and TransferJet [3]. The experimental result presented in Section 5 is also shown as specification of 2DC.

Fig. 1 shows that transmission system based on 2DC technology can reduce EBR by reducing the power consumption of analog radio frequency (RF) components as well as TransferJet and Passive Wi-Fi, while achieving a room-scale communication range.

The major factors of power consumption are classified into the following two components: the analog RF component to generate RF signal transmitted from the antenna and the digital component to process baseband signals. The EBR can be drastically reduced as the analog RF power consumption is reduced. As the
evidence, the EBR of TransferJet and Passive Wi-Fi are at least 1–2 orders of magnitude lower than other schemes in the dashed box shown in Fig. 1.

Recently, we have proposed a 2DC tile system [7]. By connecting tiles side by side, the communication range is extended to a room-scale. It enables signal transmission/reception by all the devices laid on the floor, and even on any furniture covered with 2DC sheets. The devices can communicate with low emission power density of $-41.3$ dBm/MHz [8]. This is significantly lower than the antenna power of conventional ZigBee devices, which is $0$–$+20$ dBm in a 2-MHz channel bandwidth. Hence, the EBR can be reduced in 2DC.

As shown in Fig. 1(a), 2DC tile systems can provide longer communication range than TransferJet. We have recently analyzed the relationship between the number of tiles connected and signal-to-noise ratio (SNR). Assuming $-41.3$-dBm/MHz power density transmitted, up to 17-m communication range can be achieved with 50-cm square 2DC tiles, while 20-dB SNR is required [9].

Higher transmission rate of 2DC, compared with Passive Wi-Fi, is due to wide frequency range it occupies. It can operate as ultra-wideband (UWB) radio system [8]. In this paper, we show that the transmission rate higher than 70 Mbps can be achieved with the EBR of 1.7 nJ/bit.

The EBR of 2DC is measured by using TransferJet devices on 2DC system. The symbol duration of TransferJet is shorter than the delay spread of 2DC system, which causes the inter-symbol interference (ISI). By optimizing the symbol rate, the ISI can be reduced and transmission rate can be increased.

### 3 Previous works of two dimensional communication

2DC is a short-range communication scheme using a sheet-like waveguide [10]. The 2DC sheet guides electromagnetic waves and generates evanescent (non-radiative) waves above its surface. It enables low emission and wide frequency range communication between transceivers laid on the sheet surface. The system can be constructed as “an extremely low power radio station (ELPRS)”, which is defined as a radio station that generates an electric field intensity less than 35 $\mu$/m at 3 m distant from the radio equipment [11]. While the requirement on the intensity of the radiated electromagnetic field is satisfied, the frequency range that an ELPRS occupies is not restricted.

![Fig. 2. 2DC tile system installed on the floor of a room.](image)
A 2DC tile system is shown in Fig. 2. Two-dimensional area (floor) can be covered with multiple parallel 1-D chains or with a long meander chain of 2DC tiles [11]. To keep the available signal power almost constant across the entire tile system, amplifier is embedded in each base layer and compensates signal loss [12].

Each waveguide sheet is electromagnetically isolated from the other sheets, i.e., the guided modes of them do not interact with each other. This means that the transmitted signal reverberates inside the 50-cm square waveguide sheet. The reverberation in such a lossy small area results in a small delay spread about 8–10 ns [7]. The delay spread of ordinary indoor wireless communication, where radio signals reverberate in a room-scale three-dimensional space, is 100–150 ns on an average and generally varies an order of magnitude due to scattering and absorption by objects/people in the environment. The symbol rate of ZigBee and Bluetooth is less than 1 Mbps. Its symbol duration is greater than 1 µs which is 7–10 times longer than the average delay spread. On the other hands, since the signal propagation paths in tiles are electromagnetically almost isolated from the outside space, the delay spread is little affected by objects/people in the room.

### 4 Energy-efficient signal transmission on 2DC

While the symbol duration is longer than the average delay spread, signal can be transferred with acceptable ISI. Thus, the devices can transmit signal at high symbol rate, which enables high data transmission rate with a single or a few carriers. The digital logic component of single-carrier transceivers can be much simplified compared with a modulation circuit for orthogonal frequency-division multiplexing (OFDM).

To avoid significant ISI, the symbol duration should generally be about 10 times greater than the delay spread of a channel. In a waveguide sheet with an 8–10-ns delay spread, a 100-ns symbol duration signal, which corresponds to 10-MHz symbol rate, can be transferred without significant ISI. Assuming complementary code keying (CCK) with 8 bit per symbol, 80 Mbps will be enabled.

As a result, the transceiver which optimizes the symbol rate for room-scale 2DC environments can communicate with low emission power density of −41.3 dBm/MHz while providing 80 Mbps transmission rate. Its communication range is at most 17 meter.

### 5 Experimental results

In this section, we present experiments to demonstrate the feasibility of low emission and high transmission rate 2DC. We measured the transmission rate of a single-carrier high-symbol-rate 2DC system, by using a commercially available TransfeJet adapter, SANWA SUPPLY ADR-TJMUBK.

TransferJet is one of ELPRSs. Its symbol rate of 280 MHz, which corresponds to a symbol duration of 3.57 ns, will undergo significant ISI in a 50-cm square sheet.

Fig. 3(a) shows the measurement environment. One of two TransferJet adapters, attached to a PC, was connected to the feeding point of 2DC sheet with a coaxial cable. The other one, attached to another tablet PC, is connected to a
proximity coupler laid on the sheet. To connect the coaxial cables, an SMA connector was soldered on each TransferJet circuit board.

We measured the transmission rate at three different coupler positions. The delay spread of the 2DC channel, from the feeding point fixed on a sheet edge to the proximity coupler, depends on the coupler position, because a standing wave is generated due to the open-edges of the sheet [7]. The delay spread was measured with a vector network analyzer (VNA) at each coupler position. While keeping the coupler position unchanged, VNA ports were connected to the feeding point and the coupler, instead of the TransferJet devices. VNA measured a scattering parameter (S-parameter) from the feeding point to the coupler in the frequency domain. It was converted into the time-domain impulse response by the inverse Fourier transform [7].

The three measurement results are shown in the transmission-rate versus delay-spread plot, Fig. 3(b). The EBR also shown in the same graph was calculated from its transmission rate and power consumption of 118 mW, that was published in [2]. At a coupler position where the delay spread was 3.9 ns, the transmission rate

![Fig. 3. Transmission rate and EBR were evaluated on a 2DC sheet by using a pair of TransferJet adapters. (a) The measurement environment and (b) measured results.](image)
achieved 71.1 Mbps and the corresponding EBR was 1.7 nJ/bit. This result is also plotted in Fig. 1. The transmission rate slower than the original TransferJet is due to the bit error more frequently caused by a significant ISI. By optimizing the symbol duration, the transmission rate will be maximized at any arbitrary coupler position on the entire 2DC area.

6 Conclusion

In this paper, we reported a low power consumption and high transmission rate communication system based on 2DC technology. We evaluated the feasibility of our proposed communication system by using TransferJet adapter. The experimental system achieved 71.1 Mbps transmission rate while its EBR was 1.7 nJ/bit. Thus, the feasibility of low EBR and high transmission rate 2DC was demonstrated. It will enable to exchange large amount of data across a WSN with a practical battery life of distributed nodes.

Acknowledgments

This work was supported in part by the Strategic Information and Communications R&D Promotion Programme (SCOPE) 155103003.