A Method to Assign Spread Codes Based on Passive RFID Communication for Energy Harvesting Wireless Sensors Using Spread Spectrum Transmission

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ABSTRACT
Considerable research has been conducted on systems that collect real-world information by using numerous energy harvesting wireless sensors. The sensors need to be tiny, cheap, and consume ultra-low energy. However, such sensors have some functional limits, including being restricted to wireless communication transmission. Therefore, when more than one sensor simultaneously transmits information in these systems, the receiver may not be able to demodulate if the sensors cannot accommodate multiple access. To solve this problem, a number of proposals have been made based on spread spectrum technologies for resistance to interference. In this paper, we point out some problems regarding the application of such sensors, and explain the assumption of spread codes assignment based on passive radio frequency identification (RFID) communication. During the spread codes assignment, the system cannot work. Hence, efficient assignment method is more appropriate. We consider two assignment methods and assessed them in terms of total assignment time through an experiment. The results show the total assignment time in case of Electronic Product Code (EPC) Global Class-1 Generation-2 which is an international standard for wireless protocols and the relationship between the ratio of the time taken by the read/write command and the ratio of total assignment time by the two methods. This implies that more efficient methods are obtained by considering the time ratio of read/write command.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Wireless communication; I.2.9 [**Robotics**]: Sensors.

General Terms
Design, Experimentation.

Keywords
Energy harvesting wireless sensor, transmit only, spread spectrum transmission, passive RFID communication.

1. INTRODUCTION
Researchers have considered systems that can collect varied forms of real-world information through wireless sensors, with the eventual aim of realizing a ubiquitously networked society [1, 2]. For such a system, energy harvesting wireless sensors which require no battery and no maintenance are expected [3, 4]. The features of ideal wireless sensors include not requiring a battery, smallness in size and low cost. However, sensors of this sort exhibit poor communication performance because of the simplified circuit. To address this issue, researchers have proposed compensating for such instability by using receivers composed of high-performance computers [5, 6]. Action RFID systems use a variety of wireless sensors. They only transmit and do not conduct bidirectional communication. They are used for inventory management, human management, localization and investigation of temperature, humidity, vibration, etc. In general, energy harvesting wireless sensors have limited functionality, including being restricted solely to transmission. Hence, they are action RFID tags that do not contain batteries. They actively send signals regarding each identification or sensed data. However, these signals conflict with signals from other sensors because action RFID tags cannot cooperate with other sensors [7]. The application of spread spectrum communication to active tags has been proposed in order to address this problem [8]. Spread spectrum communication is known to be resistant to interference. It multiplies baseband signals and spread codes, which are pseudo-random patterns, and sends these to the receiver. Spread signals are demodulated using spread codes. For example, the IEEE802.15.4 (ZigBee), which is the standard protocol for sensor networks using spread spectrum communication on the physical layer. If a unique spread code is assigned to each sensor, the wireless system enables code division multiple access (CDMA). Figure 1 shows the concept underlying CDMA. For

MOBIQUITOUS 2015, July 22-24, Coimbra, Portugal

DOI 10.4108/eai.22-7-2015.2260267

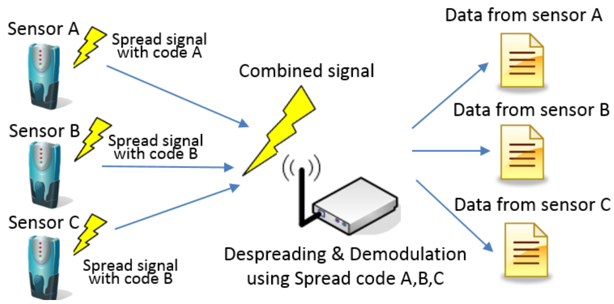

Figure 1. The concept underlying code division multiple access.

example, Wideband CDMA (W-CDMA), which is an air interface standard in third-generation (3G) mobile telecommunication, uses this multiple access method.

Our research objective in this paper is to apply spread spectrum communication to energy harvesting wireless sensors. This research theme has already been discussed in the literature, but some research challenges persist. The first is reducing energy consumption through spread spectrum transmission [9]. The process of spread spectrum transmission requires more computation process in general. The second outstanding research issue is to solve the near-far resistance problem in sensors. This is caused by disabling real-time electric power control [10]. The third issue is receiver to estimate frequency offset of sensors [11]. Frequency offset is caused by poor oscillator performance and decrease communication performance. Our assumption and requirement mentioned in Section 2 includes other research task which is increasing the speed of spread code assignment.

The remainder of this paper is organized as follows: in Section 2, we introduce past research on energy harvesting wireless sensors, as well as the assumptions made regarding and the requirements of systems that can assign spread codes based on passive RFID communication. In Section 3, we propose our spread code assignment method, and test it in terms of total assignment time through an experiment described in Section 4. We offer our conclusions in Section 5.

2. RELATED WORK ON WIRELESS SENSOR SYSTEMS

In this section, we first introduce the energy harvesting wireless sensors related to our research, and then explain our approach to spread spectrum communication.

2.1 Energy Harvesting Wireless Sensor

Energy harvesting wireless sensor can extract electrical energy from solar energy, vibration energy, Wi-Fi radio, RF energy transferred from a passive RFID reader/writer [12], and so on. RF energy transferred from a passive RFID has expanded into other field of research. A method whereby analog sensing information is superimposed on the backscatter of passive RFID communication has also been proposed [13], as has a reconfigurable, battery-assisted wireless sensor using passive RFID communication [14].

A prototype of wireless sensor developed by our research team is shown in Figure 2. This sensor has three main features: 1) transmission with multiple subcarriers [15], 2) zero-energy configuration by passive RFID communication, and 3) hybrid active-passive transmission.

2.2 Assumption and Requirements

In our research, we assume a system that can collect real-world information using energy harvesting wireless sensors. The

Figure 2. A prototype of wireless sensor.

sensors embedded in various living spaces transmit signals to the system regarding their IDs and the sensed data. This system has four requirements:

1. Ability to handle multiple energy harvesting wireless sensors
2. Spread spectrum transmission
3. The use of sensors that cannot cooperate with others
4. The absence in the sensors of a real-time control channel

The first factor is necessary to realize the gathering of real-world information, which is highly dense. The second factor enables interference resistance and multiple access, whereas the third and fourth factors are due to the specification whereby such sensors can only transmit information.

2.3 Spread Code Assignment Based on Passive RFID Communication

With regard to our assumption and requirements, it is difficult to assign spread codes statically to sensors when they have been manufactured because the number of spread codes is limited against the numerous sensors. A spread code assignment protocol is proposed to utilize limited number of spread codes for IVC (inter-vehicle communication) [16]. Each vehicle communicates its surrounding vehicles and recognizes each spread codes and selects unused code. However, energy harvesting wireless sensor can only transmit, hence [16] is not able to be applied to the system which we assume. Figure3 illustrates the code assignment to numerous transmit only sensors embedded in the system by passive RFID communication. This approach uses the function of zero-energy configuration, which is suited to our prototype energy harvesting wireless sensor. In this approach, the RFID reader/writer assigns unique spread codes to each sensor on regular basis. The allocation information is managed and shared with the receiver. The sensors send information through spread spectrum transmission.

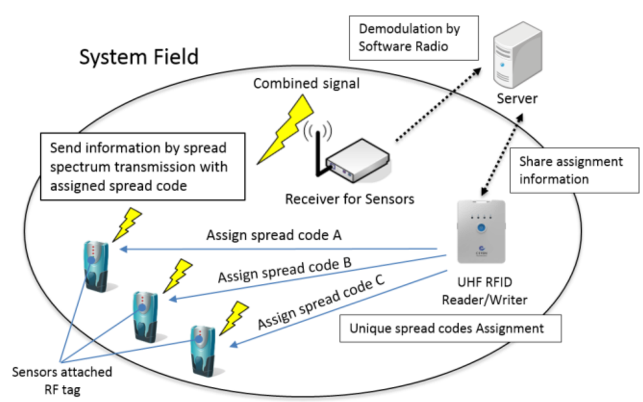

Figure 3. The concept underlying spread code assignment based on passive RFID communication.

3. PROPOSED SPREAD CODE ASSIGNMENT METHODS

While spread codes are assigned to sensors by the RFID reader/writer, the wireless sensor system cannot work. If the system is required to collect sensor information at all times, it is desirable that the ratio of system operation should be kept high. To consider increasing the speed, it is necessary to consider total assignment time. However, assuming that the RFID reader/writer assigns spread codes to sensors which have no control channel, no research has been conducted on reducing total assignment time. Hence, we devised two assignment methods, as shown in Figure 4. One involves (a) Assigning spread codes to each sensors, manually. Whereas the other involves (b) Checking current spread codes used by sensors and modifying overlapped spread codes.

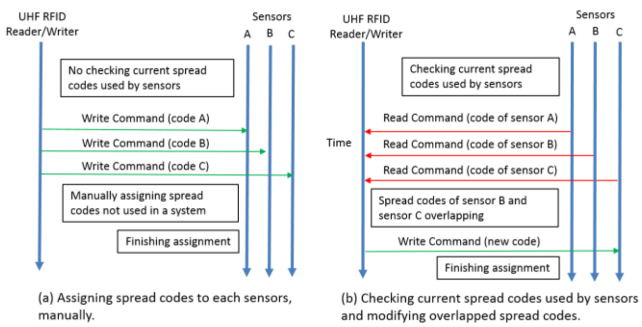

Figure 4. Structure of (a) Assigning spread codes to each sensors, manually and (b) Checking current spread codes used by sensors and modifying overlapped spread codes.

4. EVALUATION

4.1 Experimental Setup

We tested our two proposed spread code assignment methods in terms of total assignment time. It is not attempted to measure total assignment time by preparing some sensors because the number of sensors are limited. Therefore, we measured the time taken for the read/write command for one RFID tag. The total assignment time was estimated based on these values. We implemented a measurement program involving an ultra-high frequency (UHF) RFID reader/writer (CEYON SKY900BLE), and an RF tag (NXP SL3S4011) attached to our prototype wireless sensor shown in Figure 5. In this setup, the transmission protocol was Electronic Product Code (EPC) Global Class-1 Generation-2 (EPC Gen-2). In EPC Gen-2, the read/write command is carried out by a 16-bit block unit. Table 1 shows the results. We see that the write command took more than twice as long to execute as the read command. In practical scenarios, the time taken by the read/write command depends on the specification of the reader/writer with regard to EPC Gen-2.

Table 1. Results of times taken by the read and write commands.

Block	Read command time (ms)	Write command time (ms)
1	586.1413	1417.1740
2	686.8161	1546.0260
3	626.1280	1536.0800

Figure 5. The measurement program used: UHF RFID reader/writer (CEYON SKY900BLE), and RF tag (NXP SL3S4011) attached to prototype wireless sensor.

4.2 Evaluation in Terms of Total Assignment Time

For method (a), involving the assignment of spread codes to each sensor, the total assignment time was calculated using (1):

$$T_{total(a)} = NT_{write} \qquad (1)$$

where N is the number of sensors, $T_{total(a)}$ is the total assignment time for method (a), and T_{write} is the time taken by the write command, which was calculated to be 1417.1740 ms. The total assignment time for method (b), which involved checking spread codes at any given time in order to avoid collision, the total assignment time was calculated using (2):

$$T_{total(b)} = NT_{read} + eT_{write} \qquad (2)$$

where $T_{total(b)}$ is the total assignment time for method (b), e is the average number of collision of spread codes, and T_{read} is the time taken by the read command, which was 586.1413 ms. The number of collision was calculated through a simulation. The results are shown in Figure 6. They revealed that method (b) was more efficient than method (a) in terms of total assignment time for N = 0 ~ 500. The total assignment time for (a) increased linearly, whereas that for method (b) increased nonlinearly with a downward convex-shaped graph. The greater the number of spread codes, the more efficient (b) is because collisions decreased.

We also considered the ratio of the time taken by the read/write command to the total assignment time for each of (a) and (b). This is because the command time depends on the specifications of the reader/writer in EPC Gen-2. The relationship was obtained from (3), which consisted of (1) and (2):

$$\frac{T_{total(a)}}{T_{total(b)}} = \frac{N\left(\frac{T_{write}}{T_{read}}\right)}{N + e\left(\frac{T_{write}}{T_{read}}\right)} \qquad (3)$$

The result for N=500 is shown in Figure 7. This shows that the relationship between the ratio of the read/write command time and the ratio of the total assignment times of methods (a) and (b) are in proportion, and the degree of graph increase with the number of spread codes. This relationship shows that how to determine which of (a) and (b) is more efficient than the other from the viewpoint of total assignment time against read/write command time.

4.3 Discussion

We saw that the time taken by the write command was more than twice of that taken by the read command. This may have been because the RFID reader/writer verified the written blocks when it carried out the write command. Figure 6 shows that method (b) was more efficient. Furthermore, it shows that the greater the number of spread codes, the more efficient total assignment time is. However, the spread codes were too long to demodulate the spread signal in real time. In Figure 7, if the ratio of the read/write command time were known, we can make a judgement which is more efficient method in (a) or (b).

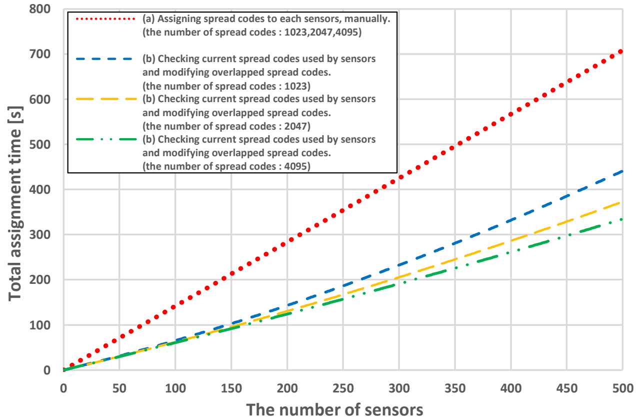

Figure 6. Relationship between the number of sensors and total assignment time for different methods and numbers of spread codes.

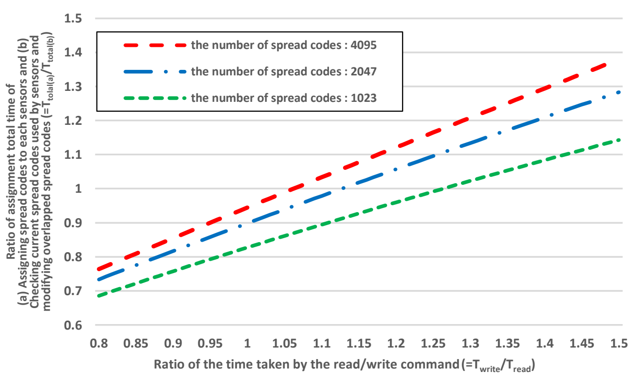

Figure 7. Relationship between the ratio of read/write command time and the ratio of total assignment time for (a) assigning spread codes to each sensor and (b) checking current spread codes used by sensors and modifying overlapped spread codes.

5. CONCLUSION

The application of spread spectrum communication has been researched in recent times in order to handle a large number of energy harvesting wireless sensors that can only transmit signals. In such communication, a unique spread code is needed for each sensor but the number of spread codes is limited. It is difficult to assign spread codes statically to sensors when they have been manufactured. To address this issue, we proposed in this paper two spread code assignment methods based on passive RFID communication. In our design, the spread codes of sensors are managed by a wireless sensor system and are assigned to sensors to avoid code collision. Furthermore, in order to render this communication efficient, we tested two spread code assignment methods in terms of total assignment time: (a) assigning spread codes to each sensor, and (b) checking spread codes at any given time to avoid collisions. Using read and write command times as the measure for our experiments, we calculated the total assignment time for both methods. The results showed that assignment method (b) was more efficient because the write command for both methods required more than twice the time taken by the read command. However, the time taken by the read and write commands depends on the specifications of the reader/writer. Hence we investigated the ratio of the time taken by the read/write command to total assignment time for methods (a) and (b). From the relationship, we can make a judgement which is more efficient assignment method in (a) or (b) if the ratio of the read/write command times are known.

6. ACKNOWLEDGMENTS

This work was supported by JSPS KAKENHI Grant Numbers 25240010 and 25730054.

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