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Temporal coverage mechanism for distinct quality of monitoring in wireless mobile sensor networks

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ABSTRACT

Previous studies have proposed various uses of wireless sensor networks, including military, surveillance, environmental monitoring, and health care applications. Sensor network coverage is a major concern because it reveals how well an area is monitored. However, the number of sensor nodes in a monitored area must be sufficient for achieving full spatial coverage. When the monitored area cannot be fully covered because of few sensor nodes, continually monitoring the specific area is a considerable challenge. Full temporal coverage, in which every point of a given monitored region is monitored within a specific time interval, can be achieved if mobile sensors are precisely scheduled. In this study, an energy balance mechanism is designed to maintain full temporal coverage in a monitored area. Furthermore, the monitoring lifetime is lengthened. The experimental results revealed that the proposed mechanism supports full temporal coverage and improves the quality and lifetime of monitoring.

1. Introduction

Applications of wireless sensor networks (WSNs), such as military, surveillance, and environmental monitoring, present coverage concerns [1–4]. The full coverage of a sensing region can be classified into spatial and temporal types. In full spatial coverage, an entire network area can be monitored at any given time. A WSN is regarded as providing full temporal coverage if every point in a region is monitored by sensors in each given period. From the perspective of monitoring, abundant sensors in a monitored area can ensure more density and sensitivity for events sensing. Thus, if a region is more crucial than another region, such as an intersection and rendezvous, it might require more sensors or longer monitoring. In this study, the quality of monitoring (QoM) for a region represented the importance of this region; a more crucial region had a higher QoM. In general, various regions might exhibit distinct event occurrence probabilities or distinct importance; thus, the QoMs of these regions are distinct. To achieve efficient monitoring, the QoM for various regions is considered reliable for addressing the problem of conserving resources [5].

Numerous studies on maintaining full spatial coverage have been conducted [6–11]. Full spatial coverage can be achieved using well-deployed static sensors [6,7] or mobile sensors required for efficient adjustment [8,9]. However, these approaches require many mobile sensors to achieve full spatial coverage. Energy efficiency has also been considered in the literature [7,10,11] and has been applied in environments in which dense sensors are employed. For the environment used in this study, the number of sensors was considerably lower than that required for full spatial coverage. Previous studies have discussed full temporal coverage mechanisms in WSNs in which sensors monitor partial areas in each time unit but monitor the entire area

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in a given duration. For full temporal coverage, Liu and Cao [12] and Liu et al. [13] proposed full temporal coverage mechanisms by arranging the sleep cycle of dense static sensors. The mechanisms were based on numerous well-deployed static sensors. Wang et al. [16] proposed mechanisms to deploy in a temporal coverage environment. Chang et al. proposed that mobile sensors move alternately to achieve full temporal coverage [14], [15]; however, they did not consider the diversity of QoM in those regions. The contributions of this study to the literature on temporal coverage are presented in Table 1.

This paper proposes a distributed mechanism for maintaining full temporal coverage of an environment with distinct QoMs for various regions by using deployed mobile sensors themselves. The goal of the mechanism is to lengthen the monitoring lifetime by using only a few mobile sensors and limited energy. The proposed mechanism enhances surveillance quality and balances and reduces the energy consumption of mobile sensors. Thus, the QoM of the proposed mechanism is greater and more reliable than that of existing mechanisms and the monitoring lifetime is longer.

The remainder of the study is organised as follows. Section 2 introduces the system model and problem formulation. Section 3 explains the concept and details of the proposed mechanism. Section 4 presents the rules for applying the proposed algorithm. Section 5 provides a performance evaluation of the proposed protocol. Section 6 concludes this study.

2. Network environment and problem formulation

This section introduces the network environment and problems addressed in this study. In the environment, n mobile sensors, $m_1, m_2, m_3, \ldots, m_n$, were deployed in a given Area A with a length and width of A_{length} and A_{width}, respectively. The communication range of a sensor, r_c, is twice the length of the sensing distance, r_s (i.e., $r_c = 2r_s$). Area A can be partitioned into numerous equal-sized hexagonal cells. The length of each edge in the hexagonal cell equals r_s. When a mobile sensor is located at the centre of a cell, the mobile sensor can monitor the entire cell and communicate with mobile sensors located at the centres of neighbouring cells. A hexagonal cell is more effective than a rectangular cell because the overlapping region between two neighbours is less. In addition, a hexagonal cell is more effective than a circular cell because the location of a cell is easier to represent. Thus, using an equal-sized hexagonal cell simplifies the locations of sensors for communicating and monitoring. In the proposed protocol, when the number of mobile sensors is higher than the number of cells in the environment, some mobile sensors can sleep to reduce energy consumption. When the number of mobile sensors is less than that of cells, the maximal number of sensors in each cell is one. Each cell can be assigned coordinates (x,y) to represent the location of its centre. Thus, Area A can be defined using (1), where x_{max} and y_{max} are the values of $\lfloor A_{length}/\sqrt{3}r_s \rfloor + 1$ and $\lfloor (2A_{width})/(3rs) \rfloor + 1$, respectively. The centre of $(1,1)$ is $r_s/2$ from the left edge of the area and $\sqrt{3}\ r_s/2$ from the top edge of the area. Fig. 1 presents an example of the environment in which (x_{max}, y_{max}) equals $(6,4)$. When a mobile sensor m_i locates cell (x,y), it moves to the centre of cell (x,y). The cell (x,y) is then monitored by the mobile sensor because the entire cell is in the sensing range of m_i. Otherwise, certain points in cell (x,y) remain unmonitored by sensor m_i. Moreover, because the communication range is twice the sensing range, the mobile sensor in a cell can communicate the status of the sensors to one-hop distance neighbours.

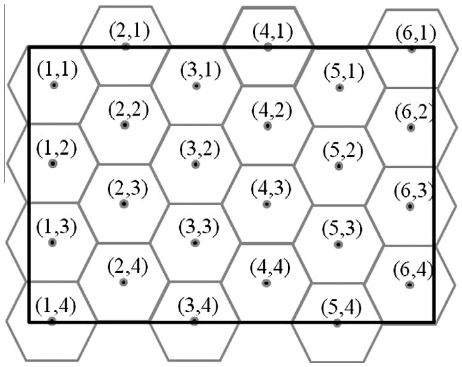

Fig. 1. An area is separated by a number of hexagonal cells.

$$A = \{(x,y) | 1 \leqslant x \leqslant x_{max}, 1 \leqslant y \leqslant y_{max}\} \quad (1)$$

In a network environment, events occur when the statuses of monitoring items are changed. For instance, in an exhibition, supermarket, or library, some items are removed or disorganised; after this event is detected, the items can be managed or reordered. If the events are detected and managed in less than the required service period, the quality of service is acceptable. The quality of service can be high if events are detected early. Furthermore, some items are more popular or attractive than others. Thus, these items should be detected more frequently. Therefore, in the exhibition, deploying mobile sensors to monitor the entire area is necessary, and some regions, called crucial regions, should be monitored frequently.

The assumption in this study is that each mobile sensor knows its location and the information for an area, such as the QoM of each cell and the boundaries of the area. Although the number of sensors might be adequate for monitoring the entire area, after monitoring for a period of time, certain mobile sensors might fail because of energy exhaustion. To extend the monitoring lifetime, the remaining mobile sensors must help monitor other regions. Before the problems and the mechanism intended to solve these problems are introduced, definitions are provided.

In this study, the QoM of each cell is either low or high. A cell with a low QoM exhibits less event occurrence or less crucial events than a cell with a high QoM and is thus called a normal cell. Conversely, a cell exhibiting a high QoM is called a crucial cell. Let Q_{dv} be the demarcation value of QoM in the environment. If a cell (x,y) possesses a high QoM, the QoM of that cell, $Q(x,y)$, must be higher than Q_{dv}; otherwise, it must possess a $Q(x,y)$ that is less than or equal to Q_{dv}. Let C^{impt} and C^{noml} represent the sets of crucial cells and normal cells, respectively. In other words, when the QoM of a cell (x,y) is high, it is included