Journal of Network and Computer Applications 35 (2012) 2068–2080

Contents lists available at SciVerse ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Performance evaluation of selective and adaptive heads clustering algorithms over wireless sensor networks

Khalid A. Darabkh [a,*], Shereen S. Ismail [b], Mohammad Al-Shurman [c], Iyad F. Jafar [a], Eman Alkhader [d], Mamoun F. Al-Mistarihi [e]

[a] Department of Computer Engineering, The University of Jordan, Queen Rania Street, Amman 11942, Jordan
[b] Department of Electrical Engineering, Al-Zaytoonah University of Jordan, Amman 11733, Jordan
[c] Department of Network Engineering and Security, Jordan University of Science and Technology, Irbid 22110, Jordan
[d] Department of Electrical Engineering, Isra University, Amman 11622, Jordan
[e] Department of Electrical Engineering, Jordan University of Science and Technology, Irbid 22110, Jordan

ARTICLE INFO

Article history:
Received 9 April 2012
Received in revised form
25 July 2012
Accepted 20 August 2012
Available online 2 September 2012

Keywords:
Wireless sensor networks
New clustering algorithms
Object tracking
Energy consumption
Tracking error
Target speed
Sensor density

ABSTRACT

Target tracking in wireless sensor networks can be considered as a milestone of a wide range of applications to permanently report, through network sensors, the positions of a mobile target to the base station during its move across a certain path. While tracking a mobile target, a lot of open challenges arise and need to be investigated and maintained which mainly include energy efficiency and tracking accuracy. In this paper, we propose three algorithms for tracking a mobile target in wireless sensor network utilizing cluster-based architecture, namely adaptive head, static head, and selective static head. Our goal is to achieve a promising tracking accuracy and energy efficiency by choosing the candidate sensor nodes nearby the target to participate in the tracking process while preserving the others in sleep state. Through Matlab simulation, we investigate the performance of the proposed algorithms in terms of energy consumption, tracking error, sensor density, as well as target speed. The results show that the adaptive head is the most efficient algorithm in terms of energy consumption while static and selective static heads algorithms are preferred as far as the tracking error is concerned especially when the target moves rapidly. Furthermore, the effectiveness of our proposed algorithms is verified through comparing their results with those obtained from previous algorithms.

1. Introduction

Wireless sensor networks (WSNs) are distributed self-organizing embedded systems which consist of a large number of low cost, low power, and intelligent sensor nodes deployed over a certain geographical area (Tsai et al., 2007; Abbasi and Younis, 2007; Arora et al., 2004). The sensor nodes are small in size and can perform many important functions out of which sensing, data processing, and wireless communication with other nodes (Akyildiz et al., 2002; Yong-Min et al., 2009). WSNs have been employed in a large spectrum of applications such as wildlife animal monitoring, military intrusion detection, surveillance disaster management, and healthcare monitoring systems (Yick et al., 2008; Khemapech et al., 2005; Padmavathi et al., 2010). Due to its importance, mobile target tracking is considered a milestone of all these applications (Kim et al., 2006; Fayyaz, 2011). The goal is to detect a target, such as a vehicle or a person, entering a monitored area by sensor nodes, estimate its location and report that to the base station, as well as track its new locations as the target moves across a certain path (Karl and Willig, 2005; Tseng et al., 2003). The sensors' readings which concern about the target locations are to be aggregated through the cooperation of these nodes. Consequently, the aggregated data is to be forwarded to the base station with a certain regularity (Li et al., 2008; Jung et al., 2011). The task of tracking a target in WSNs is a challenging matter due to the following issues (Tsai et al., 2007; Yang and Sikdar, 2003; Younis and Fahmy, 2004): sensors resources limitation (especially energy, communication bandwidth, and processing capabilities), a large number of sensors need to be deployed and coordinated efficiently, and redundant data which need to be handled professionally since adjacent sensor nodes often observe the same mobile target (the event of interest) and may have similar data. In the literature, various algorithms have been proposed for mobile target tracking in WSN. In the following subsection, some of the relevant contributions have been summarized in this field.

1.1. Related work

There have been a lot of research ideas proposed for detecting, localizing, and tracking a single or multiple targets inside an area filled with sensor nodes. The main target tracking approaches in

* Corresponding author. Tel.: +962 77 9103900.
E-mail address: k.darabkeh@ju.edu.jo (K.A. Darabkh).

1084-8045/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jnca.2012.08.008

WSNs can be summarized as follows (Tsai et al., 2007; Fayyaz, 2011; Bhatti and Xu, 2009): tree, prediction, mobicast message, centralized, cluster, as well as hybrid approaches. Furthermore, it has been also reported that energy consumption during the tracking process is the key concern in the majority of the proposed algorithms due to sensor's energy constraints (Bhatti and Xu, 2009; Garcia et al., 2010). Tree based approaches for target tracking are widely known in the literature. In these approaches, the hierarchical trees are formed dynamically according to the target movement in the network area (Tran and Yang, 2006; Zhang and Cao, 2004). A well-known tree based tracking approach is Optimized Communication and Organization (OCO) which provides self-organizing and routing capabilities of sensor nodes during the tracking process which are performed in four phases (Tran and Yang, 2006): position collecting, processing, tracking, and maintenance. The major drawback of this approach is that the border sensor nodes are activated permanently. Therefore, the energy of these nodes may be depleted rapidly. Generally, tree based approaches are not scalable and need to be evaluated from tracking accuracy perspective (Bhatti and Xu, 2009).

In prediction based approaches, a sensor can predict the future movement of the target based on a history of its past locations over time. Thus, the sensors' states (active, sleep) can be easily controlled (Garcia et al., 2010). The main idea of these approaches is that the sensor nodes use past estimated locations collected during the target movement to activate a specific set of nodes in a range where the target may move toward (Xu et al., 2004). Such algorithms are usually complicated to be implemented on sensor nodes with limited capabilities (Ren et al., 2008) (i.e., power, computation, and memory storage for target history). Additionally, such algorithms need recovery mechanisms to deal with unavoidable target missing situations that occur due to unpredictable direction and speed changes of the mobile target (Bhatti and Xu, 2009; Raza et al., 2009). In (Xu et al., 2004), the authors rely on the prediction method to propose a prediction-based energy saving (PES) scheme to predict the future movement of the target being tracked with less frequency of keeping the sensors awake. In other words, the sensor nodes that are expected to discover the target are activated while other nodes are deactivated and put into sleeping mode. Hence, energy saving is achieved. If the prediction mechanism misses the target location, PES proposes a primitive error handling technique that disseminates wake up control messages within a larger area to find the target back. However, the energy cost of such algorithm is quite expensive specifically when tracking irregular moving targets (Hsu et al., 2011).

In Wang et al. (2008), Maneuvering target tracking-Mobicast (MTT-Mobicast) algorithm is proposed to utilize the mobicast message target tracking approaches. It is a spatiotemporal multicast algorithm that distributes messages to the sensor nodes located in spatial zones that evolve over time in a predictable manner. However, the design of the MTT-Mobicast protocol faces challenges in developing a fully distributed scheme to construct some special zones that can limit unnecessary retransmissions and ensure receiving the required message by all participated nodes. Such algorithms face also a challenge in dealing with the situation when the target is missing. Furthermore, maintaining the spatiotemporal constraints in Mobicast based algorithms needs to be further investigated and deeply evaluated.

In Tynan et al. (2009), the authors have proposed two mechanisms, utilizing the centralized method, called weighted average localization (WAL) and maximum signal strength localization (MSSL) to evaluate their performance over WSN. In these mechanisms, all sensor nodes are kept in active state to monitor the target that passes by within their sensing area. The nodes that detect the mobile target should forward their data directly to the base station to estimate the target location as employed in Sarna and Zaveri (2010) and Tsukamoto et al. (2009). However, the major drawback of the centralized approaches is that the energy consumption per node is high resulting in unacceptable overall system energy consumption (Sarna and Zaveri, 2010). In addition, the tracking accuracy is severely affected by the target speed since the sampled data needs to be forwarded to the base station while in the mean time the target may move to a new distance. The longer the time it takes for all data messages to reach the base station, the larger the distance travelled by the target, leading to an increase in localization error (Tynan et al., 2009). Unlike the previous mechanisms, the minimal contour tracking (MCT) algorithm is an energy-aware target tracking algorithm proposed in Jeong et al. (2007). This algorithm conserves network energy by minimizing the number of sensor nodes that participate in the tracking process. MCT algorithm updates the tracking area that contains the mobile target during its trajectory by modeling the vehicular kinematics (i.e., vehicle's current position, speed, and direction) to prune out from the area where the target cannot visit and accordingly reduce the number of working sensors. The authors have named the tracking area, where the mobile target can move starting from its current position, the minimal contour. In this approach, the energy consumed in communication is improved. However, MCT algorithm still keeps all the nodes in the contour alive without any adopted sleep scheduling mechanism (Jiang et al., 2008).

In Ren et al. (2008), energy efficient tracking (EET) algorithm has been proposed to reduce energy consumption for tracking a mobile target in WSN using static clustering architecture. The concept of clustering architecture is briefed by grouping the sensor nodes into clusters and accordingly electing a cluster head for each cluster (Jung et al., 2011). However, in this algorithm, the cluster heads rotate among the sensors in each cluster during the tracking process to evenly distribute the energy load among them. Sensor members of the cluster can communicate and send their data to their own cluster head. The cluster head in turn forwards the aggregated data to the base station. The EET algorithm has also introduced an event driven sleep scheduling mechanism in which the sensor members turn between awake and sleep states according to corresponding messages received from their cluster heads. EET algorithm gives tradeoffs between real time and energy efficiency by maximizing the number of sensor nodes that are put into sleep mode outside the tracking area. However, the major disadvantage of this algorithm is the high communication overhead introduced by sleep scheduling messages.

Hybrid tracking approaches for target tracking merge more than one approach, of previously described ones, for the sake of mitigating their individual drawbacks as much as possible (Bhatti and Xu, 2009). A well-known algorithm that follows these approaches is hierarchical prediction strategy (HPS) which combines a cluster approach along with a certain prediction algorithm (Wang et al., 2008). In HSP, the cluster is formed using Voronoi division and the next location of mobile target is predicated upon least square method (LSM). The major disadvantage of such algorithms is the extra complexity added upon combing target tracking approaches based on the application requirements leading to an additional increase in the system energy consumption. In addition, other overheads in such algorithms are not evaluated yet (Bhatti and Xu, 2009).

1.2. Our methodology and contributions

All algorithms mentioned above have been proposed to track a moving target focusing on the trade-off between energy