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Lifespan prolonging location-wise predetermined deployment strategy for visual sensor networks

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ABSTRACT

Visual sensor networks are widely used for surveillance, environmental monitoring and tracking. However, due to the funneling effect, visual sensor nodes (SNs) close to the sink tend to deplete their energy sooner than SNs farther away from the sink resulting in energy hole problem. This energy hole problem significantly increases the unbalanced energy usage among SNs and leads to premature decrease in network lifetime. Initially, we analyzed network lifetime and found number of relay nodes and their location has significant influence on limiting the energy hole problem and enhancement of network lifetime. Based on the principle of energy balancing, derived from this analysis, we develop a heterogeneous SNs deployment strategy leading to an enhancement of network lifetime. Exhaustive simulation is performed, primarily to measure the extent of achieving our design goal of limiting memory and computation overheads, enhancing network lifetime while attaining energy balancing. We also measure the effect of placement errors on the performance and show that even in presence of placement error the performance is comparable with the other competing scheme. Further, the simulation results show that our scheme does not compromise with other network performance metrics such as end-to-end delay and throughput while achieving the design goal. Finally, all the results are compared with a competing scheme and the results confirm our scheme's supremacy in terms of both design performance metrics as well as network performance metrics.

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1. Introduction

The relentless pace of technological augmentation in image sensors led to the emergence of a new ubiquitous paradigm – visual sensor network (VSN) (Soro and Heinzelman, 2009). VSNs consist of tiny SNs called camera nodes, which integrate the image sensor, embedded processor and wireless transceiver (Soro and Heinzelman, 2009). Images are captured and extracted by the camera nodes. The embedded processor performs further image processing operations such as image compression or even image characterization to take decisions based on the images. This processed imagery data is then finally sent to the appropriate destination in the network, which forwards the imagery data to the base station or sink. The convenience of deployment and the capability to communicate via wireless links made them attractive in many applications such as monitoring system (Durmus et al., 2012), intrusion detection (Diop et al., 2013), and people tracking (Coşar and Çetin, 2014).

Since, VSNs are battery operated and require a lot of energy to capture and process images compared to wireless sensor network (WSN), as a result, the VSN as a whole must minimize the energy usage to enable untethered and unattended operation for an extended period of time. Therefore, a critical consideration in designing such VSNs is conserving energy to maximize the post-deployment network lifetime. The rate of energy depletion in the network primarily depends on the deployment nature of the SNs which further depends on the application environment (Akyildiz et al., 2007). As the SNs are expensive and their operations are significantly affected by their positions so, in VSNs location-wise predetermined deployment is generally more preferable compared to random deployment.

1.1. Motivation

Most of the prior researches on VSN primarily focused on energy conservation issue for a given specific scenario. One important way of energy conservation by limiting energy hole is through balanced energy consumption. Unbalanced energy consumption in any part of VSN may stop functioning of that part leading to a phenomenon known as energy hole problem (Halder and Ghosal, 2013). The energy hole generally occurs near to the

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sink due to the funneling effect i.e., the SNs closer to the sink have to forward more packets than the SNs at the periphery of the network. The energy hole problem has worse impact on a VSN than a conventional WSN. While energy consumption is dominated only by data transmission and reception in a WSN, VSN consumes extra power on image sensing, processing, and storage operations. Because of such additional energy consumption, the energy hole problem inherent in WSNs has a drastic impact on the network lifetime and leads to its premature decrease in VSN. To circumvent this, care should be taken that SNs are deployed in such a manner that energy dissipation of all SNs takes place uniformly ensuring load balancing throughout the network. Since SNs are expensive, deploying more redundant SNs closer to the sink only for energy backup does not seem to be a cost-efficient option.

1.2. Contributions and organization

Many works have been done so far on how to use energy efficiently in VSNs (Charfi et al., 2009). All of these works have been conducted through different approaches e.g., distributed power management scheme (Zamora and Marculescu, 2007; Casares and Velipasalar, 2011; Dieber et al., 2011), energy conservation by avoiding redundant data (Soro and Heinzelman, 2007; Costa and Guedes, 2013), deployment strategy (Yildiz et al., 2011; Li et al., 2012) etc. Each type of these approaches has their strengths and limitations. In most of the existing VSN energy management works, the proposed deployment strategies guaranteed the increase in network lifetime. However, most of these deployment strategies do not belong to the category of location-wise predetermined deployment strategy. Here, by location-wise predetermined strategy we mean not only the number of SNs to be deployed in a network area is determined a priori but the precise locations are also predetermined. Most of the existing works are silent about the exact locations of placing the SNs, which is an important criteria for applications like smart surveillance of public or remote areas and smart homes for babies. A preliminary version of our work was reported in Halder and Ghosal (2014). We extend our earlier work in several aspects. Our main contributions in this paper are as follows:

- We analyze the method of controlling network lifetime by balancing the energy consumption by considering deployed heterogeneous SNs in terms of performing tasks (sensing and relaying). It is found that judicious distribution of number of heterogeneous SNs has significant role in controlling network lifetime.
- Based on the analysis, energy balancing principle is derived and that in turn is used for deciding the number of heterogeneous SNs to be deployed along with their deployment locations so that network lifetime is maximized.
- We propose a heterogeneous SNs deployment scheme and achieve energy balancing to a greater extent.
- Performance of the scheme is evaluated through quantitative analysis. In quantitative analysis both ideal and realistic scenarios are provided for showing the impacts of routing and medium access control (MAC) protocols on the performance of the strategy.

The rest of the paper is organized as follows. In Section 2, literature review is elaborated. The network architecture considered for the present work is presented in Section 3. Analysis on network lifetime is done in Section 4. A heterogeneous SNs deployment scheme exploiting the derived principle of energy balancing is proposed in Section 5. In Section 6, the performance of the scheme is evaluated by providing simulation results. Finally, the paper is concluded with some mention about the future scope of the work in Section 7.

2. Literature review

The works addressing the solutions of efficient usage of energy and subsequent enhancement of network lifetime, mentioned in the previous section are elaborated in this section.

Zamora and Marculescu (2007) proposed a Coordinated Distributed Power Management (CDPM) policy to lower the energy usage of SNs for VSN. Their proposed policy assumes that each SN is awake for a while, after which the VN decides whether it should take the low-power state based on the timeout status of its neighboring SNs. Alternatively, SNs can decide whether to enter the low-power state based on voting from other neighboring SNs. The CDPM policy includes dynamic and adaptive timeout thresholds, hybrid CDPM, two-hop broadcast information dissemination, and remote wakeup. Simulation results show substantial improvement in terms of energy usage. However, longer delays are introduced in packet delivery because during the sleep phase SNs cannot communicate and packets cannot be transmitted until the relay or destination SNs wake up.

Soro and Heinzelman (2007) proposed several cost-metrics for the selection of a set of SNs that provide images used for reconstructing a view from a user-specified view point for three-dimensional environment. Two types of metrics are considered by the authors viz. coverage-aware cost-metrics, and quality-aware cost-metrics. The coverage-aware cost-metrics consider the remaining energy of the SNs and the coverage of the indoor space, and favor the selection of the SNs with higher remaining energy and more redundant coverage. The quality-aware cost-metrics favor the selection of the SNs that provide images from a similar view point as the user's view point. Thus, the proposed SN selection methods provide a trade-off between network lifetime and the quality of the reconstructed images.

Yildiz et al. (2011) addressed the problem of SNs deployment in heterogeneous VSNs to provide video panorama with a trade-off between cost and resolution. The problem is modeled as mixed-integer program which solves the problem in two phases viz. master problem, and sub-problem in a recursive manner. Among these phases, master-problem finds a solution to an initial set of points while sub-problem determines new points that need to be covered and pass them to the master-problem. The solution provided is optimal, based on the piece-wise linear approximation of Field-of-View (FoV) arcs. Experiment results indicate the superiority of the proposed algorithm with respect to multi-perspective coverage compared to existing approaches. Although the proposed algorithm ensures enhanced full multi-perspective coverage, but, the algorithm is not energy efficient.

Li et al. (2012) proposed a two-tier heterogeneous node deployment strategy to prolong lifetime of a VSN while minimizing cost and limiting the effects of the energy-hole problem. Here, by heterogeneous node authors mean functional heterogeneity i.e. few nodes that are primarily responsible for capturing the image are known as SNs and rest of the nodes responsible for relaying received images from SNs are known as relay node (RN). The SNs are deployed uniformly in tier one whereas RNs are deployed using Gaussian distribution in second tier. Since the choosing of judicious number of RNs and standard deviation of Gaussian distribution in a cost-effective manner is very challenging, thus, authors proposed an optimal RN deployment strategy in terms of lifetime and cost of nodes. Although simulation results exhibit the proposed deployment strategy as cost-effective and enhanced network lifetime is achieved, however, the choosing of number of RNs and standard deviation of Gaussian distribution is still challenging.

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