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Cross layer load balanced forwarding schemes for video sensor networks

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ABSTRACT

In this paper, we propose two cross layer geographic forwarding schemes which address congestion in wireless video sensor networks (VSN) to provide reliable video delivery. The first scheme Load Balanced Reliable Forwarding (LBRF) introduces the notion of local load balancing where a sensor dynamically determines the next hop among the alternative neighbors providing positive advancement towards the sink by considering the balance of their buffer occupancy levels at the time of delivery. LBRF utilizes a modified version of SMAC where the packet structure as well as the operation of SMAC is modified for the accurate monitoring of the buffer occupancy conditions of the neighbors. The second scheme Directional Load Balanced Spreading (DLBS) combines local and direction-based (spatial) load balancing approaches to provide more reliable and faster video delivery by benefiting from the advantages of both approaches. The performance of the forwarding schemes are compared using simulation with two geographic routing schemes where one applies no load balancing and the other applies spatial load balancing. The results show that both LBRF and DLBS provide more reliable video delivery as compared to other schemes, whereas DLBS is more reliable and faster as compared to LBRF. In addition, DLBS provides more energy efficient video delivery in terms of energy expenditure per successfully delivered frame to the sink as compared to LBRF and the other two schemes.

1. Introduction

Wireless sensors have evolved to bear camera devices for supporting new applications such as video surveillance, target tracking, battlefield intelligence and environmental monitoring. The necessity of providing a high Quality of Service (QoS) requirement for video traffic imposes extra difficulties besides carrying such traffic over a limited-bandwidth, error-prone wireless channel by the sensors with limited energy budget. Hence, video sensor networks (VSNs) [1] emerged as a new research topic in the area of wireless sensor networks (WSNs).

In VSNs, the logical unit of the communicated data is a video frame, which is composed of video packets. If no encoding schemes such as FEC [2] are utilized in the network, all packets of a video frame are required to be received by the sink node for a successful frame delivery. The performance of the video application, such as the success of object identification or the quality of tracking, highly depends on the reliable delivery of frames to the sink. The reliability concept mentioned in this context considers the amount of video frames successfully delivered to the sink in a given sensor network.

The load on a video sensor is determined by the amount of frames created by the sensor itself and by the amount of packets that the other sensors relay over it with the aim of delivery to the sink. Since the sensing range of nodes often overlaps, the same event is usually detected by multiple sensors. The created traffic in these networks is in the form of unpredictable bursts of video frames triggered by sensed events, resulting with a sharp increase in the data input

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rate of a sensor. In addition, the output rate of a sensor decreases due to contention caused by many concurrent transmission attempts. In these cases, combined data input rate becomes greater than the output rate of a sensor and data packets starts to accumulate in its buffer causing local congestions. Depending on the buffer size and the duration of the congestion, a buffer overflow is likely to occur causing video packets to be dropped by the sensor.

Since VSNs operate in a multi-hop manner, congestion taking place at a certain area may diffuse to the whole network and degrade the network performance drastically. The congestion may cause a large amount of packet loss, which in turn diminish the network throughput. As a consequence, the reliable detection of events is hampered since the desired event features sensed by many nodes could not be reliably communicated to the sink. Moreover, the congestion increases the energy expenditure of the sensor nodes which in the long run also hinders the reliable reporting of the events due to energy depletion.

A candidate solution to reduce the possibility for a sensor to be congested is to decrease the load on the sensor, by reducing the amount of data to be created or to be relayed. The amount of data created by a sensor in case of event detection is assumed to be predetermined by the application. Therefore, we focus on reducing the amount of data relayed over a sensor, which is mainly determined by the routing algorithm. In order to decrease the likelihood of congestion in a sensor, the buffer occupancy levels of each sensor should be kept as low as possible. Applying load balancing approaches in the routing decisions is a possible option to reduce the buffer occupancy levels.

A centralized routing algorithm [3–5] may calculate the optimal load balanced routing decisions for a given sensor network after deployment and disseminates the routing information to the sensors. In each topology change, the routing decision should be recalculated and disseminated to the sensors. Hence, centralized approaches are not appropriate for the distributed and the dynamic nature of wireless sensor networks. In the distributed approach [6,7], the routing layer algorithm may distribute the load in any sensor evenly among its appropriate neighbors and may decrease the buffer occupancy levels throughout the network.

Since the location and the occurrence of an event in a sensor network are random, the load and therefore the buffer occupancy levels of the sensors in the neighborhood of any sensor are dynamic and may not be even at the time of decision for a relay. Hence, evenly distributing the load without cross-layer assistance may result with a further degradation of the unevenness in the buffer occupancy levels in the neighborhood. Moreover, in some cases the routing algorithm may choose a neighbor sensor with no available buffer space as a relay. In that case, the corresponding data unit is dropped at the relay sensor which causes bandwidth and energy waste. The situation is worse in terms of energy waste if the dropped data unit has traveled over many hops in the network up to this point. In order to decrease the possibility of such a routing decision and prevent from data drops in the relay sensor, the routing layer should use cross-layer information about the buffer occupancy levels of the sensors in the neighborhood. If the routing layer of a sensor has fresh information about the buffer occupancy levels, it can determine the relay which improves the evenness of the buffer occupancy levels in the neighborhood. However, there may be still some cases in which the buffer occupancy information about a neighbor is stale when actually there does not exist any available buffer space in that neighbor. In such a case, if the routing layer determines that neighbor as the relay, the delivery of the data results with a data drop at the relay. Hence, there should be a handshaking mechanism confirming the existence of the available buffer space in the determined relay sensor before the delivery of the data. If the existence of the available buffer space is not confirmed, the delivery of the data should be cancelled. In this paper, we propose two cross-layer forwarding schemes, which integrate routing and medium access control (MAC) layers in sensor networks to provide reliable event detection by means of load-balancing.

Our proposed routing schemes are based on geographic routing. Geographic routing is commonly regarded as highly scalable and energy efficient, which makes it an attractive solution for routing in wireless sensor networks [8,9]. The routing decision at each node is based on the destination's position and the position of the forwarding node's neighbors. Greedy-forwarding [10–12] is a type of geographic routing in which the relay for the data is determined in a greedy manner regarding the aim of minimizing the number of hops to reach the sink by maximizing the advancement towards the sink. The drawback of these routing strategies is that many sensors choose the same sensor as their relays and create congestion by concentrating the traffic on these preferred relays. In a sample scenario depicted in Fig. 1a, the sender nodes (4, 5, 6) tries to forward their data to the same sensor node (1), although there are two other possible relay candidates (2, 3) which can directly send their data to the sink. This generic scenario around the sink can be replicated all around the network.

In our first forwarding scheme, namely LBRF (Load Balanced Reliable Forwarding), the relay node is dynamically determined according to the current buffer occupancy levels of the neighbors that provide positive advancement towards the sink. The buffer occupancy information in the neighborhood is obtained by a piggybacking mechanism embedded in the underlying MAC protocol. Our scheme

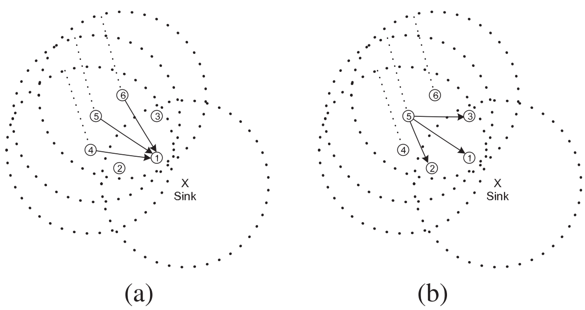

Fig. 1. A comparison of forwarding strategies. (a) Greedy forwarding and (b) LBRF.