Routing Protocols for Wireless Multimedia Sensor Networks: Challenges and Research Issues

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Abstract. Due to miniaturization of hardware and availability of low-cost, low-power sensors, Wireless Sensor Network and Multimedia Sensor Network applications are increasing day by day. Each application has a specific quality of service and experience requirements. The design of routing and MAC protocol which can fulfill the requirements of the application is challenging given the constrained nature of these devices. Considerable efforts are directed towards the design of energy efficient QoS-aware routing protocols. In this article, we present state of the art review of routing protocols for Wireless Multimedia Sensor Networks while addressing the challenges and providing insight into research issues.

Keywords: Wireless multimedia sensor network · Routing protocols · QoS · QoE · Geographic routing

1 Introduction

Wireless Sensor Network (WSN) has emerged as one of the most prominent technologies with applications in almost all walks of life like industrial process control, health monitoring, target tracking, vehicle traffic monitoring, surveillance etc. [5,22]. WSN is treated as one of the most important technologies in surveillance and monitoring applications [6,7].

Recent developments in low-cost CMOS cameras, microphones and small-scale array sensors which ubiquitously captures multimedia contents have promoted the development of a low-cost network of video sensors. These sensors can be integrated with traditional WSN [10,21,24]. Wireless Multimedia Sensor Network (WMSN) is capable of capturing, processing and disseminating visual information over a network of sensor nodes. Capturing of multimedia contents from specialized sensors incurs a higher cost than traditional scalar sensors. Video data transmission requires high bandwidth due to a large number of bits that are required to represent the video. It also results in higher energy consumption for transmission. Most applications of WMSN like mission critical surveillance are real-time in nature where timely delivery of the information is very critical for the success of the application. Routing and MAC protocols assume a critical role here.

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A routing protocol is responsible for forwarding the packet over the most suitable path. Routing protocols in WSNs Differ depending on the application and network architecture. Protocols for traditional WSN like LEACH [20], PEGASIS [18], SPIN [16], Directed Diffusion [2] etc... were either based on energy efficient delivery or content based delivery of the sensed information. Similar approaches are not suitable for WMSN where Quality of Service (QoS) requirements like timely delivery and reliability of the application is of prime importance. Several efforts were made to design QoS-aware routing protocols where the routing decision was stationed on either energy efficiency, deadline of the packet, reliability, packet type or combination of these parameters. The objective of this article is to study working principle of these protocols, compare them, and provide insight into their selection and further research issues.

2 Routing Challenges for WMSN

A WMSN is a resource constrained heterogeneous collection of tiny sensor devices. A typical architecture of WMSN contains scalar sensor nodes, multimedia sensors, multimedia processing hubs for in-network processing [3]. All devices operate on limited power supply making it difficult to deploy complex protocols in operation on these devices. A routing protocol needs to be energy efficient in general over specific requirements of the application. Besides limited energy, there are other factors like limited memory and processing capabilities that hinder the goal of achieving application QoS.

WMSNs are characterized by dense deployment leading to redundancy in sensing and transmission. While redundant transmission can be considered as a type of multipath forwarding providing reliability, it consumes critical resources like bandwidth and energy. In network processing techniques like data fusion might help in reducing the redundancy. In typical WMSN, correlated video contents from different sensors can be fused together or visual contents can be represented in meaningful scalar quantity to reduce redundancy. However, these techniques increase the amount of processing in the network and introduce latency, which complicates the QoS fulfillment for delay sensitive applications.

Sensor nodes are prone to failure. Improper assignment of routing and sensing task might drain energy on few nodes quickly leading to change in network topology. Load balancing remains a desired characteristics of a routing protocol. Many applications of WMSNs are concentrated towards monitoring or surveillance of certain area. Due to high deployment density, the same event triggers many sensors. In case event of interest, affected sensors are required to report the event as quickly as possible to the base station which might lead to congestion in the network. Handling congestion with limited available tools is a challenge in the design of the protocol.

Multimedia content like video or audio needs to be encoded before transmission in the network. Compressed contents generally create chunks of diverse importance, eg. video compression typically creates key frames and difference frame where key frame carries more information than its counterpart. Packets carrying key frames expects better reliability in transmission. Differential handling of packets based on the high-level description needs special attention at routing and MAC layer. Mission critical applications like process monitoring are delay sensitive in nature. Every packet can have an associated deadline within which the packet should be delivered to the destination.

The routing protocol in WMSN has to deal with challenging task of providing variable QoS guarantee depending upon whether the packet carries control information, low-rate scalar data or various high rate video traffic. Each of the traffic class has its own requirements which must be taken care by the routing process. The task becomes challenging due to lack of global knowledge, limited energy, and computational ability of the nodes.

3 Classification of Routing Protocols

Traditionally routing protocols for WSN were classified into three categories based on underlying network structure [4]:

– Flat: All nodes assumes identical roles
– Hierarchical: Nodes will play different roles
– Location-based: Position of the nodes are exploited to aid packet routing

Based on the protocol operation, they can be classified as:

– Multipath-based: Protocols identifying multiple paths
– Query-based: Nodes propagates query for data
– Negotiation-based: Negotiation messages before actual packet forwarding to suppress redundant forwarding
– QoS-based: Satisfy certain QoS metrics when delivering data
– Coherent-based: In-network processing (aggregation) based forwarding

The same classification holds for WMSN but the requirements and thus, metric changes due to change in the type of applications. Protocols proposed specifically for QoS awareness includes Sequential Assignment Routing (SAR) [23], Energy-Aware QoS Routing (EAQoS) [1], Directional Geographic Routing (DGR) [8], RAP [19], RPAR [9], SPEED [14], Multipath Multi-SPEED (MMSPEED) [12], Power Aware SPEED (PASPEED) [26]. Typically, there is no IP-like addressing scheme in WSN. If location information is available, routing protocols can utilize it to reduce the latency and energy consumption of the network. Geographic routing protocols work under the assumption that each node is location aware. In sensor networks, such location-awareness is necessary to make the sensor data meaningful. It is, therefore, natural to utilize geographic position of the node in packet routing. Most of the routing protocols for WMSN like SPEED, PASPEED, RAP, DGR, and MMSPEED uses location information packet forwarding. These protocols are specifically designed for WMSN to fulfill either real-time delivery or reliability or power-awareness or combination of these parameters. Several surveys were conducted involving comparison of routing protocols for WMSNS [4,13,17].

4 QoS Aware Protocols

Most WMSN applications generate real-time traffic. The real-time transmission has specific QoS requirements like deadline-driven transmission, reliability, and Quality of Experience (QoE) on end user part. The routing protocols used should be capable enough to fulfill these demands. Many QoS based routing protocols were proposed in the literature to support QoS transmission of multimedia traffic. They mostly deal with delay and reliability requirements of the application. They assure delivery of packets in time by assigning priority based on deadline to reach destination [14,25,26]. Shorter the deadline to reach the destination, higher is the priority. Based on the importance, different packets may have different reliability requirements. Protocols which deals with providing reliability to the packets had two primary options. They either sent multiple copies of the packet over multiple disjoint paths or estimated the path quality of multiple paths and mapped packets [11] on either of that path based on reliability requirements. These protocols differ in the way multiple paths were computed and the way path quality was estimated.

EAQoS assumes that the transmission of image and video data through WSN requires both energy and QoS awareness. The proposed protocol provides required QoS to real-time traffic at the same time support best effort traffic. It looks for a delay-constrained path with the least cost. The cost is a composite metric involving many parameters like the distance between the nodes, residual energy, time until battery drainage, relay enabling cost, sensing-state cost, max connections per relay, error rate etc. A path is to be chosen from all available path which meets the end-to-end delay requirement of real-time traffic and maximizes the throughput for best effort traffic.

RAP [19] is geographic routing protocol using Velocity Monotonic Scheduling(VMS) policy for packet scheduling in a node. Every packet request some velocity with which it should be transmitted to meet the delay requirements. Each packet is expected to be delivered within deadline if it can travel at the requested velocity. The packets are prioritized based on the requested velocity. Higher the velocity requirement, higher will be the priority of the packet. Packets are forwarded using geographic forwarding. All greedy geographic routing protocols suffer from void/hole where no further progress is possible. RAP re-routes the packets around void by using perimeter routing mode as used in GPSR [15]. The packets which can not meet the deadline even if it transferred over fastest path are bound to miss the deadline. Such packets are dropped to avoid wasting bandwidth.

Transmission power affects the transmission delay of the packets. Experiments were performed by O. Chipara et al. in Real Time Power Aware Routing (RPAR)[9] to measure the effect of transmission power on communication delay. The observations was that increase in transmission power increased the delivery velocity of the packet. Power control is at the core of RAP. For each packet to be forwarded, the required velocity is computed based on remaining deadline and distance to destination. Possible forwarding nodes are evaluated at certain power level. Based on transmission power required, the energy requirements for transmission is estimated. If none of the neighbors could provide required velocity, RPAR starts power adaptation, which dynamically increases the transmission power to increase velocity provided by that node. Nodes which are already working at maximum transmission power are ineligible for power adaptation. The transmission power of a node is decreased if it satisfies velocity requirement of a packet. Transmission power is reduced to alleviate congestion. However, power reduction does not solve the congestion issue. Packet redirection towards non-congested area is required at the network layer to handle congestion.

Directional Geographical Routing (DGR) [8] is a multipath routing protocol designed to support streaming of video over WSN. It assumed H.26L encoded video to be transmitted. The network is assumed to be unreliable. The reliability is provided by protecting the transmission using FEC. To cater to high bandwidth demands of video transmission, the video stream was separated into multiple streams which can be transferred in parallel over multiple disjoint paths. DGR constructs the application-specified number of multiple disjoint paths to the destination and mapped these FEC protected streams on to it. This lead to energy balancing across the network and better QoS and QoE achieved due to transmission over multiple paths.

SPEED [14] is a static priority deadline-driven routing protocol. It uses Stateless Non-deterministic Geographic Forwarding (SNGF) as the primary routing mechanism. The real-time communication is achieved by maintaining desired delivery speed. Unlike few other QoS-aware routing protocol, SPEED does not require any specific support from at MAC layer and can work with any MAC layer protocol. It diverts traffic at routing layer and locally regulates packets sent to the MAC layer. Thus, it maintains the desired delivery speed across sensor networks. The SNGF chooses the next node that supports desired delivery speed. Neighbor tables are maintained by exchanging beacons carrying location information. Routing tables are not required to maintained as the next hop is selected from 1-hop neighborhood. The memory required is thus proportional to Neighbor Set (NS). Delay of a link between two nodes is estimated by measuring the time between data packet sent and ACK received. Unlike other traditional approaches, congestion in the network is estimated by the delay of the link instead of the queue size. SPEED ignores the energy available on next hop node while making a routing decision. PASPEED [26] is a power aware version of SPEED which maintains the energy available on each neighbor and exploits this information while choosing the next node.

Felemban and Lee in [11,12], proposed Multi-path and Multi-Speed Routing Protocol (MMSPEED), which provide QoS differentiation in timeliness and reliability domain. Service differentiation in timeliness domain is provided by multiple network-wide speed options as compared to single speed provided by SPEED. Variable reliability is offered by probabilistic multipath forwarding depending on packet's reliability requirement.

Almost all geographic routing protocols are reactive protocols as they maintain 1-hop neighborhood information. This very local information helps them to reduce the memory requirements but decreases the accuracy of path estimation,

Table 1. Comparison of routing protocols

Routing protocol	Performance metrics	Packet prioritisation	Time management	Reliability support	Hole bypassing/void avoidance	Location awareness	Congestion control support	MAC prioritisation	Load balancing
RAP	End-to-End deadline miss ratio	Velocity Monotonic Scheduling	Packet carries slack deadline in header and updated every hop	No	Uses perimeter mode of GPSR	Yes	No support	IEEE 802.11e	No
RPAR	Energy Consumption, Dead line miss ratio	Yes (based on required velocity)	Packet carries slack deadline in header and updated every hop	No	Increase power to cover void else perimeter routing	Yes	Stop increasing power to control congestion	No	No
EAQoS	Throghput, Energy	RT and NRT	No	No	No	No	No	No	Between NRT and RT traffic
SPEED	End-to-End delay, Dead line miss ratio, Energy consumption, overhead	Yes (based on dealine and distance to sink)	Delay estimated as RTT - Rec overhead	No	Backpressure re-routing	Yes	1.locally drop packet 2. packet rerouting	Not needed	Yes by dispersing packet to large relay area
PASPEED	End-to-End delay, Dead line miss ratio, Energy consumption, overhead	Yes (based on dealine and distance to sink)	Delay estimated as RTT - Rec overhead	No	Backpressure re-routing	Yes	1.locally drop packet 2. packet rerouting	Not needed	Yes by dispersing packet to large relay area
MMSPEED	Average end to end delay, Overhead, Reliability	Yes (based on speed value)	Packet carries slack deadline. Delay estimation by marking packets	Yes (multi-path forwarding)	Backpressure re-routing	Yes	Drop packets and backpressure	IEEE 802.11e	Multipath routing
DGR	Average delay, Reliability, PSNR	No	No	Yes (multi-path routing)	Uses right hand thumb rule	Yes	No due to load balancing	No	Multipath routing

thus, increasing the chances of encountering void in the network. They fail in predicting the presence of void on selected path due to lack of global knowledge. A QoS-aware geographic routing protocol was proposed in [25] which was based on SPEED but maintaining 2-hop neighborhood. The 2-hop neighborhood information helped in estimating the presence of void early in the network. It led to the reduction in end-to-end delay and more number of packets meeting deadline.

Many routing protocols for WMSN exist in literature. A comparative analysis of routing protocols is presented in Table 1.

5 Conclusions

WSN and WMSN applications has specialized hardwares and diverse requirements. Generic solutions may not necessarily be optimal. Highly specific solutions are advocated for efficient working of an application. Routing protocols remains a critical design decision for any application. In this article, we provided an overview of WSN and WMSN and factors that affect the design of routing protocols. Several protocols are explained in brief highlighting its working principle and shortcomings. A summary of these protocols is also provided to compare them on a variety of aspects.

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