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Mobile Multimedia Sensor Networks: Architecture and Routing

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***Abstract*—Recent advances in the fields of wireless technology and multimedia systems have exhibited a strong potential and tendency on improving human life by enabling smart services in ubiquitous computing environments. This paper investigates a mobile multimedia system through combining various technologies, such as wireless sensor networks, embedded multimedia system and node mobility. In particular, we will employ some powerful sensor node with both mobility and multimedia functionalities, which can be controlled by contextual information collected by other systems to enable interactive multimedia services. The new architecture is called mobile multimedia sensor network (MMSN) in this paper. A routing scheme named mobile multimedia geographic routing (MGR) is specially designed to minimize energy consumption and satisfy constraints on the average end-to-end delay of specific applications in MMSNs. Simulations verify the MGR's performance to satisfy QoS requirement while saving energy for MMSNs.**

I. Introduction

Recent advances in the fields of wireless technology, multimedia communications and intelligent systems have exhibited a strong potential and tendency on improving human life in every facet, including entertainment, socialization, education, and healthcare. To enable smart multimedia services in a mobile and ubiquitous environment, video surveillance system may interface with other wireless technologies, such as wireless sensor networks (WSNs), wireless multimedia sensor networks (WMSNs) [1]–[3], and body area networks [4], etc. With hardware advances, this paper investigates the employment of some powerful sensor node which is equipped with both mobility and multimedia functionalities, and proposes *Mobile Multimedia Sensor Networks* (MMSNs). When controlled by contextual information collected by other systems, MMSNs can further support interactive and mobile multimedia services. In this case, the marketing opportunities for advanced consumer electronics and services will expand, and more autonomous and intelligent applications will be generated. Yet, various research issues regarding node mobility, coverage, and multimedia streaming over mobile environments are still in clouds for MMSNs.

In this paper, we first present the architecture of MMSNs. Then, we focus on multimedia delivery with the strict quality of service (QoS) requirements. By utilizing location information, we design a routing algorithm with QoS provisioning in an energy-efficient manner. The routing algorithm is called mobile multimedia geographic routing (MGR), which are designed to minimize energy consumption and satisfy constraints on the average end-to-end delay of specific applications while constructing multiple paths to the sink node along the moving trajectory. MGR has the inherent scaling property of geographic routing, where packet-delivery decisions are locally made, and the state at a node is independent of the number of nodes in the network. Most importantly, it achieves flexible energy delay tradeoffs.

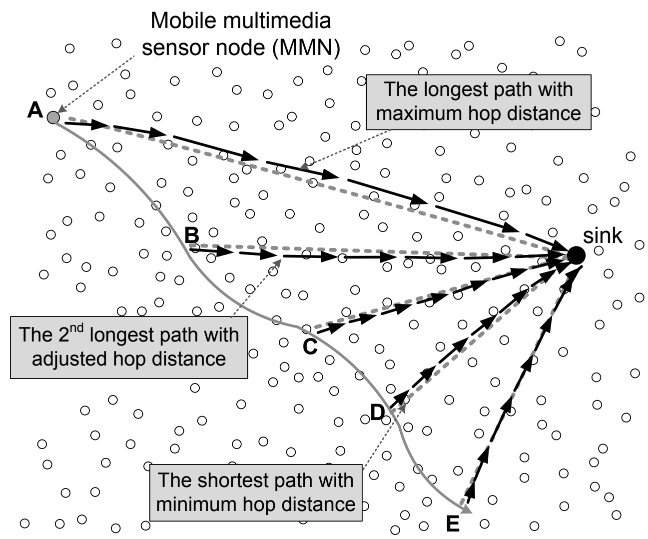


Fig. 1. A Simple Illustrative Architecture of Mobile Multimedia Sensor Network

Notation used in this paper is given in Table I. The rest of the paper is organized as follows. The architecture of MMSNs is presented in Section II. We describe the MGR scheme in Section III. Simulation model and experiment results are presented in Section IV. Section V concludes the paper.

II. Architecture of Mobile Multimedia Sensor Networks

Due to node mobility in MMSNs, some multimedia sensor nodes can move to various critical locations for collecting comprehensive information such as image or video stream. Previously, the issue of guaranteeing soft QoS delay for delivering multimedia streams while prolonging lifetime over a bandwidth-limited and unreliable sensor network is addressed by exploiting multiple node-disjointed paths, in order to achieve load-balancing, reduction of path interference, enlarged bandwidth aggregation and fast packet delivery. However, those work are targeted at multimedia transmission over

TABLE I
NOTATION

Symbol	Definition
s:	the source node.
t:	the sink node.
h:	the current node.
D_s^t:	distance from source node to sink node.
$D_{h\to t}$:	distance from current node to the sink node.
T_{hop}	the average hop delay at a sensor node.
T_{QoS}:	the application specific End-to-end delay objective.
$T_{h\to t}$:	the reserved time credit for the data delivery from current node to the sink node according to T_{QoS}.
$t_{s\to h}$:	data packet's experienced delay up to current node.
$H_{h\to t}$:	the desired hop count from current node to the sink node according to T_{QoS}
D_{hop}:	the desired hop distance for next-hop-selection in MGR
E_{hop}:	the energy consumption for one-hop data delivery
E_{ete}:	the end-to-end energy consumption for a successful data delivery

static WSNs [1]. In comparison, the proposed MMSNs have the following features:

- Traditional WSNs have the intrinsic characteristic of scalar data collection (e.g., temperature, humidity, air pressure, etc.), which is hard to elaborate some complicated events and phenomena. In MMSNs, multimedia sensor nodes can provide more comprehensive information such as pictures, text message, audio or videos.
- The merging of mobility into multimedia sensor nodes further improve the network performance, such as locating mobile nodes to an optimal positions for fast multimedia services, approaching targets for enhanced event description with high resolution image or video streams, the additional capability for exploring a larger area of sensor nodes to disseminate multimedia streams, as well as various advantages in traditional mobile sensor networks (e.g. load balancing, energy efficiency, improving fairness on the data collection, and coverage optimization, etc.)
- Though the mobility of multimedia sensor node provides the advantage, the network topology becomes dynamic, which brings difficulties in both the data communication and data management.

Fig. 1 shows a simple illustrative architecture of MMSN. When a mobile multimedia sensor node (MMN) moves in MMSNs, it periodically sends a multimedia flow at a new location. If a geographic routing scheme is used, the MMN sets up an individual path to the sink node for each multimedia flow. As time goes on, a series of paths will be built up while the MMN moves along a certain trajectory. Given the illustrative scenario shown in Fig. 1, the sequence of the constructed paths to transmit multimedia traffic to the sink could be: Path-A, Path-B, Path-C, Path-D, Path-E. If the mobility mode and multimedia collections are controlled by other systems intelligently, more and more automated applications can be generated for industry and daily life.

III. Mobile Multimedia Geographic Routing

Since our design goal is to effectively support the multimedia service in MMSNs, we consider the performance in terms of both delay and energy. First, the delay guaranteeing is treated as the goal with top priority for the QoS provisioning. Then, the energy consumption should be minimized to enlarge the life time of sensors. This motivates to exploit the energy-delay tradeoffs for the design of mobile multimedia geographic routing (MGR) scheme.

A. Analysis of Delay-Energy Tradeoffs

1) Analysis of One-Hop Delay: In this section, we analyze the latency between two neighboring nodes, which is the summation over the queuing, processing, propagation, and transmission delays:

- *Queuing delay*: For the sake of simplicity, we assume a stable packet rate in our network. Then, queuing delay is considered to be a constant for each hop, which is denoted by T_q.
- *Processing delay*: With respect to processing delay, we assume that each node incurs similar delay to process and forward one packet with constant length. The processing delay is denoted by T_p.
- *Propagation delay*: This parameter can be neglected when compared to the other delays.
- *Transmission delay*: We assume that the size of a data packet does not change between a source-sink pair, its transmission delay (denoted by T_{tx}) remains constant between any pair of intermediate sensor nodes.

Therefore, the delays taking place between any pair of intermediate nodes are considered to be similar in this paper, which can be estimated simply by $T_{\text{hop}} = T_q + T_P + T_{\text{tx}}$. Consequently, the delay between current node to the sink node is proportional to the hop count between the two nodes.

2) The End-to-end Energy Consumption: Given a constant packet size and a fixed propagation distance, we consider every sensor node will consume the same energy to forward the packet. Therefore the end-to-end energy consumption for delivering a data packet from the source node to the sink node is proportional to the number of transmissions, i.e., the hop count. The basic energy model of one hop transmission in this paper is:

$$E_{\text{hop}} = C \cdot D_{\text{hop}}^{\alpha}$$

where C is a constant value, D_{hop} is the transmission distance, and the parameter α is the path loss exponent, depending on the environment, typically is equal to 2 when free space propagation is assumed. For the sake of simplicity, C is set to 1, and α is set to 2. Then, $E_{\text{hop}} = D_{\text{hop}}^2$. Let $H_{s\to t}$ be the hop count from the source node to the sink node. Then, the end-to-end energy consumption can be estimated by:

$$\begin{aligned} E_{\text{ete}} &= \sum_{i=1}^{H_{s\to t}} E_{\text{hop}}(i) \\ &= E_{\text{hop}} \cdot H_{s\to t} \\ &= D_{\text{hop}}^2 \cdot H_{s\to t} \end{aligned} \tag{1}$$

which increases linearly with the value of D_{hop}. Motivated by an interesting feature that some sensor devices can transmit at different power levels [6], this paper assume that the sensor node has the capability of power control to reduce end-to-end energy consumption.

3) Energy-Delay Tradeoff: Typically, a geographic routing mechanism (e.g., GPSR [5]) intends to maximize packet progress at each hop in a greedy fashion. Since such a distance-based scheme introduces nearly maximal hop distance, the end-to-end delay could be minimized while more energy will be consumed based on our energy model.

However, achieving minimum delay is not beneficial for some delay sensitive applications when the minimum delay is smaller than the application specific QoS delay boundary (i.e., T_{QoS}). In the case that the earlier arrival of a data packets is not necessary, an intermediate sensor node can reduce the transmission power with a smaller transmission range for delivering packet to next hop in order to reduce energy consumption, but not too small to still be able to guarantee the delay objective.

B. End-to-end Delay Objective

Let D_s^t denote the distance between source and sink. Let R_{max} denote the maximum transmission range of a sensor node. Then, the minimum end-to-end delay is equal to $T_{min} = \frac{D_s^t}{R_{max}}$, which is realized by the use of the shortest path with maximum progress at each hop. Then, for a certain network topology, an multimedia application is allowed to adjust application-specific end-to-end delay T_{QoS} subject to the following constraint at least: $T_{\text{QoS}} > T_{min}$, otherwise the QoS delay cannot be achieved.

C. Calculating the Desired Hop Distance at Current Node

Let $t_{s\to h}$ denote data packet's experienced delay up to current node. Let $t_{current}$ denote the current time when the routing decision is being made; let t_{create} denote the time when the packet is created at the source node. Then, $t_{s\to h}$ can be easily calculated by the difference between $t_{current}$ and t_{create}. Then, the reserved time credit for the data delivery from current node to the sink node, $T_{h\to t}$, can be calculated by:

$$T_{h\to t} = T_{\text{QoS}} - t_{s\to h} \tag{2}$$

Based on $T_{h\to t}$ and T_{hop}, the desired hop count from current node to the sink node can be estimated as

$$H_{h\to t} = \frac{T_{h\to t}}{T_{\text{hop}}} \tag{3}$$

Upon the reception of data packet from its previous hop, the current node will know the position of the sink node. Then, distance from current node to the sink node, $D_{h\to t}$, can be calculated according to the positions of itself and the sink node. Let D_{hop} denote the desired hop distance for next-hop-selection. Then,

$$D_{\text{hop}} = \frac{D_{h\to t}}{H_{h\to t}} \tag{4}$$

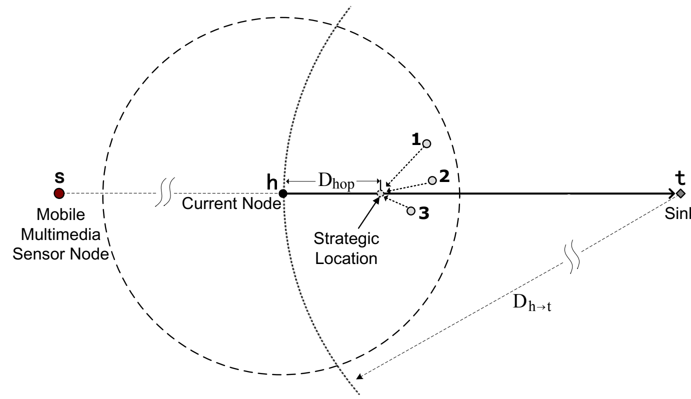


Fig. 2. Illustration of the Strategic Location Selection in MGR scheme.

D. Strategic Location for Next-hop-selection

In this paper, strategic location means the ideal location of current node's next hop. Based on D_{hop} calculated in Section III-C, the strategic location of MGR is decided as in Fig. 2

The absolute coordinates of the strategic location and a next hop candidate j are denoted by (x_s, y_s) and (x_j, y_j), respectively. Then, the distance between j and the strategic location (denoted by ΔD_j) can be calculated by

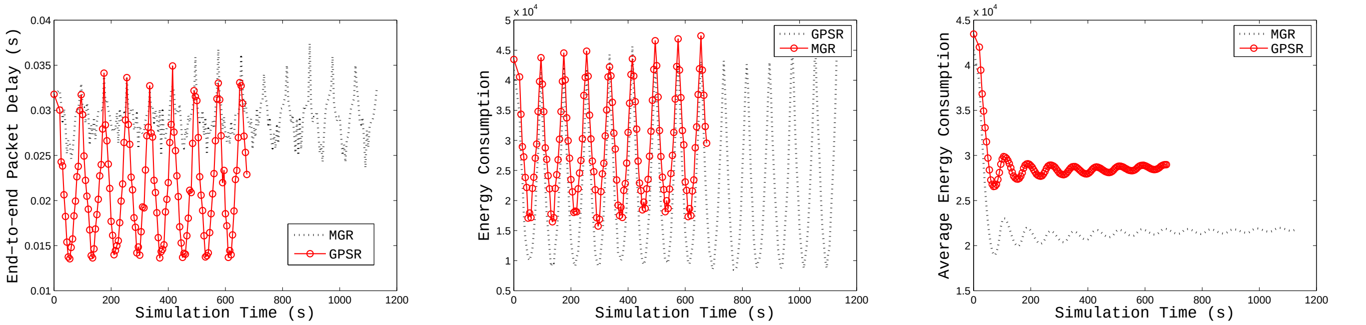
$$\Delta D_j = \sqrt{(x_s - x_j)^2 + (y_s - y_j)^2} \tag{5}$$

Algorithm 1 MGR-NextHop($\text{POS}_h, \text{POS}_t, T_{QoS}, T_{\text{hop}}$): Pseudo-code for selecting the neighbor with the minimum D_j as *NextHop*

begin
notation
h is the current node to select the next hop node;
V_h is the set of node h's neighbors in the forwarding area;
POS_h is position of the current node;
POS_t is position of the sink node;
initialization
calculate $T_{h\to t}$ based on T_{QoS} and $t_{s\to h}$;
calculate $H_{h\to t}$ based on $T_{h\to t}$ and T_{hop};
calculate $D_{h\to t}$ based on POS_h and POS_t;
calculate D_{hop} based on $D_{h\to t}$ and $H_{h\to t}$;
for each neighbor j in V_h **do**
calculate ΔD_j according to Eqn.(5);
end for
for each neighbor j in V_h **do**
if $\Delta D_j = min\ \{\ \Delta D_k \parallel k \in V_h\}$ **then**
select j as NextHop;
break;
end if
end for
Return j;

E. Next-hop-selection in MGR

A node receiving a data packet will calculate the coordinates of its strategic location. Then, MGR will select as the next hop node whose distance is closest to the strategic location, instead of the neighbor closest to the sink as in traditional geographical routing protocols. The pseudo-code of the next-hop-selection algorithm for MGR is shown in Algorithm 1.



(a) End-to-end Packet Delay (b) Energy Consumption (c) Average Energy Consumption

Fig. 3. Performance Comparison: (a) End-to-end Packet Delay; (b) Energy Consumption; (c) Average Energy Consumption.

IV. Performance Evaluation

We implement our protocols and perform simulations using OPNET Modeler [7]. The network with 2000 nodes is randomly deployed over a 2000m $\times$ 1000m field. We let the sink node stay at a corner of the field and one MMN be located at the other corner. When simulation starts, the MMN will move back and forth along the diagonal line of the network field. We assume the sink node and the ordinary sensor nodes are stationary. Our sensor node implementation has a four-layer protocol structure. The sensor application module consists of a constant-bit-rate source, which generates delay sensitive multimedia traffic with a certain QoS requirements. We use IEEE 802.11 DCF as the underlying MAC, and the maximum radio transmission range (R_{max}) is set to 60m.

We consider the following four performance metrics:

- *End-to-end Packet Delay*: It includes all possible delays during data dissemination, caused by queuing, retransmission due to collision at the MAC, and transmission time.
- *Energy Consumption*: the energy consumption for a successful data delivery, which is calculated according to Eqn.(1).
- *Average Energy Consumption*: it is a running mean of ordinate values of input statistic, which is obtained by the statistics collection mode of "Average Filter" in OPNET simulation [7].
- *Lifetime*: It's the time when the first node exhausts its energy.

The delay requirement T_{QoS} is set to 0.035s. As show in Fig. 3(a), both GPSR and MGR guarantee the QoS delay in most cases. In GPSR, paths have various delays ranging from 0.014s to 0.035s. By comparison, most of the delays in MGR change from 0.025s to 0.035s. The delay fluctuation of GPSR is much larger than MGR. It is because the GPSR does not have delay control mechanism without the consideration of MMN's up-to-dated location when it moves in the network.

As shown in Fig. 3(b) the energy consumption of GPSR is higher than that of MGR. It is because the maximum transmission range is always used by a greedy approach in GPSR. By comparison, in MGR, the end-to-end delay is softly guaranteed while the energy is still saved. Fig. 3(c) shows the comparison of average energy consumption. MGR saves about 30% energy consumption when compared to GPSR. In our experiments, the simulation time corresponding to the last data point is also equivalent to the lifetime. As shown in Fig. 3, the lifetimes of GPSR and MGR are 675s and 1130s, respectively, and MGR yields 455s more lifetime than GPSR.

V. Conclusion

In this paper, we propose mobile multimedia sensor networks (MMSNs) where mobile multimedia sensor node (MMN) is exploited to enhance the sensor network's capability for event description. Then, the tradeoffs of end-to-end delay and energy consumption for supporting multimedia service with delay QoS requirement are discussed. By utilizing location information, we design a routing algorithm named mobile multimedia geographic routing (MGR) for QoS provisioning in MMSNs. When MMN moves in the network, MGR is designed to minimize energy consumption and satisfy constraints on the average end-to-end delay of specific applications. The experiment results show the efficiency of MGR in satisfying QoS requirement while saving energy. In future, we will further improve MGR for more reliable and efficient QoS-oriented transmission scheme, and adapt MGR for the scenarios with multiple multimedia flows per source-sink pair.

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