REAL-TIME MULTICAST ROUTING IN WIRELESS SENSOR NETWORKS

Hosung Park, Jeongcheol Lee, Seungmin Oh, Yongbin Yim, and Sang-Ha Kim
Department of Computer Engineering, Chungnam National University, Daejeon, Republic of Korea

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Abstract: Real-time data dissemination to a multicast group is data delivery to each member in the multicast group within the desired time deadline. The hardest aspect of this mission is to enforce the real-time constraint in the communication between a source and the furthest member since an end-to-end delay is proportional to a physical distance in wireless sensor networks. We call it the critical distance. The critical distance should be most important constraint for real-time multicasting. That is, the delivery distance from a source to each member should not be longer than the critical distance even by any reason. However, since the traditional multicast protocols lay the strong emphasis only on the overall communication cost rather than delivery distance to each member, they may violate the real-time constraint related to the critical distance. In this letter, we propose a novel multicast protocol for real-time data dissemination.

1 INTRODUCTION

Many sensor network applications, such as battlefield surveillance and fire alert, are designed to interact between a fast changing event (He, 2005) and multiple destinations (Akyildiz, 2010) in the real world. In these applications, it is often necessary for multicast protocol to meet real-time constraint. Real-time data delivery to a multicast group, i.e. real-time multicasting, may be defined as data dissemination to each member in the multicast group within the desired time deadline.

In wireless sensor networks, unlike legacy networks, the hop count increases as the physical distance packet travels increases since the radio range of each node is bounded. The end-to-end delay is also increases due to the increase of hop count. In other words, the end-to-end delay is proportional to the physical distance packet travels (He, 2005). Therefore, the hardest part of real-time multicasting is to enforce the real-time constraint from a source node to the furthest destination in the multicast group. In view of this, we refer to linear distance between the source node and the furthest destination as a critical distance. The critical distance must be most important constraint for real-time multicasting. In other words, the delivery distance from the source node to each destination on the multicast tree must not be longer than the critical distance even by any reason.

In wireless sensor networks, multicast protocols (Wu, 2007), (Sanchez, 2007) are proposed to deliver data to multiple destinations. They try to achieve a single goal, constructing cost-efficient multicast tree that minimizes the total delivery path from the source node to all destinations. Since the traditional multicast protocols lay the strong emphasis only on communication cost rather than each delivery distance, they may violate the real-time constraint related to the critical distance.

In this letter, we propose a novel Multicast Protocol for Real-time Data dissemination (MPRD). MPRD constructs multicast tree considering the critical distance and disseminates data by spatiotemporal approach (He, 2005) via the multicast tree to satisfy the real-time constraint.

2 REAL-TIME MULTICASTING

The problem we are facing can be described as follows: a data generated by a source node is delivered to multiple destinations with real-time constraint. In other words, each of the destinations wants to receive the data within the desired time deadline. In this section, we present MPRD for achieving this goal in detail.

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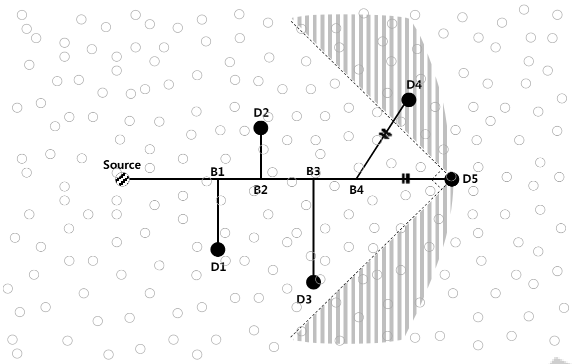

Figure 1: Real-time multicast tree construction.

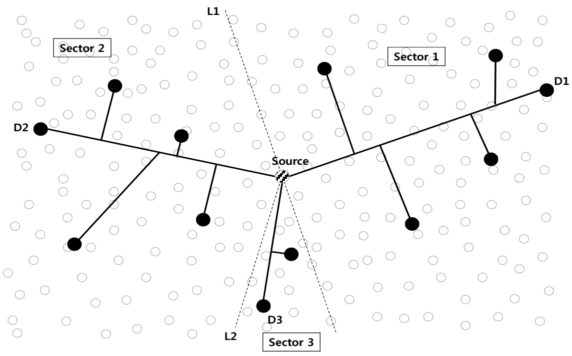

Figure 2: Dividing sectors.

2.1 System Model

MPRD, like other geographic multicast protocols (Wu, 2007), (Sanchez, 2007), employs geographic greedy forwarding as the underlying routing protocol. In wireless sensor networks, geographic multicast protocols are considered efficient, because they use only location information without the topology information of a whole sensor field. This paper is focused on multicast tree construction and data dissemination. We therefore assume throughout this paper that the source node is aware of locations of destinations. To know that information, the source node can employ destination location service schemes such as (Liu, 2006).

2.2 Real-time Multicast Tree Construction

When the source node generates real-time data, the source node constructs virtual multicast tree rooted at itself for real-time data dissemination to multiple destinations. On the multicast tree, each distance of path from the source node to all destinations has to be shorter than the critical distance. Note that the multicast tree is the virtual structure calculated by the source node instead of real structure constructed in practice.

Given a set of the destinations, MPRD connects the source node with the furthest destination in the linear path as the base line; then the path splits into branches toward other destinations. Figure 1 shows the process. MPRD draws a straight line from the source node to the D5, the furthest destination, as a base line. Other destinations, D1-D3 are connected with the base line perpendicularly since each line is shortest path to the base line.

However, some destinations may have longer path from the source node than the critical distance. Destinations located in the shaded area in figure 1 belong to this group. The D4 therefore needs to be connected with the base line in other way. When each destination is connected with the base line, MPRD checks a condition regarding the critical distance. If the path from the source is longer than the critical distance (if the destination is located in the shaded area), MPRD select a branch point on the base line closer to the source node in order to make the path from the source node to the D5 to be shorter than or equal to the critical distance. In figure 1, MPRD determines the branch point B4 which makes the distance from the B4 to the D4 and the distance from the B4 to the D5 to be equal; accordingly, the distance of the path between the source node and the D4 is equal to the critical distance.

Destinations in the opposite area of the first base line cannot be perpendicularly connected with the first base line. MPRD therefore divides the network into two or three sectors based on locations of the source node and the furthest destinations in each sectors and constructs paths separately. In figure 2, sector 1 is divided by the L1, orthogonal dotted line of the base line from the source node to the D1. A sub-tree rooted at the source node is constructed by connecting destinations in sector 1 with the base line. Sector 2 is divided by the L2, orthogonal dotted line of another base line from the source node to the D2 in residual area. The D2 is the furthest destination among all destinations but destinations in sector 1. Another sub-tree rooted at the source node is constructed by connecting destinations in sector 2 with the base line the source node to the D2. The third sub-tree is constructed by the same way in sector 3, residual area except sector 1 and sector 2.

MPRD has low computation complexity due to the simple method that each destination is perpendicularly connected with the base line after checking just one condition for the critical distance. Dividing network is also useful since it make MPRD be able to apply the simple method to each sector.

2.3 Data Dissemination

After the source node calculates the virtual real-time multicast tree, the source node sends real-time data to all destinations via the multicast tree.

In wireless sensor networks, to satisfy the desired time deadline, real-time routing scheme proposed in (He, 2005) utilize a spatiotemporal approach by which data are delivered with a delivery speed obtained from both the desired time deadline and the distance from a source to a destination. Every immediate node elects the next-hop node that is one of one-hop neighbor nodes closer to the destination than itself and has a relay speed larger than the delivery speed. Hence, by relaying data with a faster speed than the delivery speed per every hop, data can be delivered on the desired time deadline. The spatiotemporal approach can be applied due to the property that data delivery delay is dependent on the distance a packet travels in wireless sensor networks. We apply the spatiotemporal approach in order to disseminate real-time data.

After the source node calculates the virtual real-time multicast tree, the source node encapsulates calculated tree information and delivery speed in the data packet and disseminates it along the calculated multicast tree. The tree information is the locations of destinations and branch points, and the delivery speed is calculated with the desired time deadline and the distance of the base line. Note that the tree information and the delivery speeds are different at each sector.

In the data dissemination process, each node forwarding the packet selects a next-hop node among one-hop neighbors that satisfy the condition of the spatiotemporal approach. In figure 1, the data packet is delivered toward the branch point B1 via the spatiotemporal approach. When a sensor node

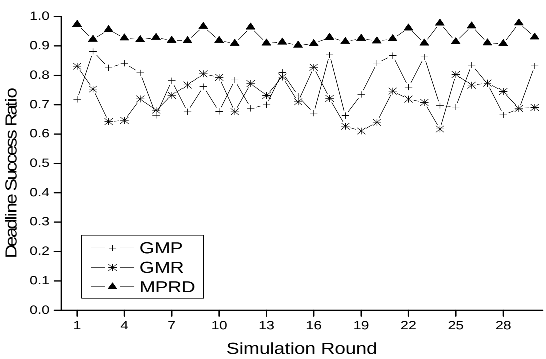

Figure 3: Deadline success ratio at each simulation round.

receives the data, if the B1 is located in radio range of the node and the node has no neighbor which is more closely located to the B1, the node elects itself as a branch node for the branch point B1. The branch node selects two next-hop nodes toward the D1 and the B2. The location of the D1 is encapsulated in packet toward the D1 and tree information except the locations of the B1 and the D1 is encapsulated in packet toward the B2. The delivery speed of the packet toward the D1, of course, could be recalculated by the distance on the path from the source node and the D1. This process is repeated until all destinations receive the data packet.

3 PERFORMANCE EVALUATION

In this section, we present simulation results to evaluate performance of MPRD. The purpose of simulations is verification that MPRD has higher success ratio of real-time data dissemination than GMP (Wu, 2007) and GMR (Sanchez, 2007) applying the spatiotemporal approach. We also evaluate energy efficiency: one of the most important issues in wireless sensor networks.

3.1 Simulation Environments and Metric

We simulate MPRD on QualNet simulator. The simulation network space is 1000 X 1000 m2. The number of nodes is 5000 and the number of destinations is 20. Transmission range of each node is 30 m. Node and destination placement follows random deployment. The source node is located at the center of network and sends 20 data packets at each round. The desired time deadline for real-time constraint is 1 second and delay of each node is randomly set between 0.03-0.1 seconds.

Deadline success ratio is average ratio of the number of destinations that receive data packets within the time deadline to the number of destinations.

3.2 Simulation Results

Figure 3 shows the deadline success ratio at each simulation round. We randomly deploy sensor nodes and destinations at each simulation round. The deadline success ratio of MPRD is distributed in closer to 1 than other protocols. In other words, MPRD has higher probability of satisfying the real-time constraint. In GMP and GMR, the data is delivered to some destinations by longer path than the critical distance. MPRD however delivers data to

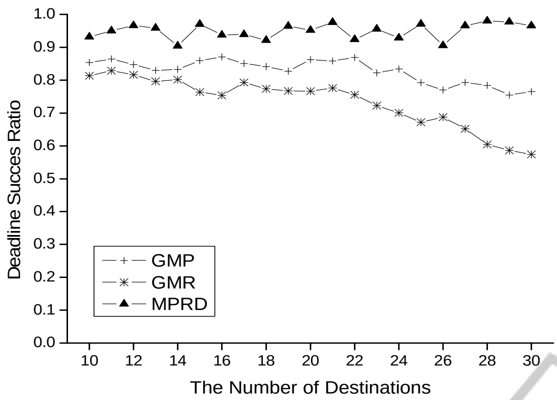

Figure 4: Deadline success ratio in respect of the number of destinations.

all destinations along paths shorter than or equal to the critical distance. Since end-to-end delay is dependent on the physical distance a packet travels in wireless sensor networks, MPRD has higher chance of satisfying the real-time constraint.

Figure 4 shows the deadline success ratio in respect of the number of destinations. As the number of destinations increases, the deadline success ratio of GMP decreases. In GMP, more paths from the source node to destinations are longer than the critical distance as the number of destinations increase, since the multicast tree becomes more complicated. In addition to the reason, GMR spends more time in order to forward data as the number of destinations increases, since computation complexity of every forwarding node increases exponentially. MPRD however is unaffected by the number of destinations, since MPRD delivers data to all destinations along paths shorter than or equal to the critical distance.

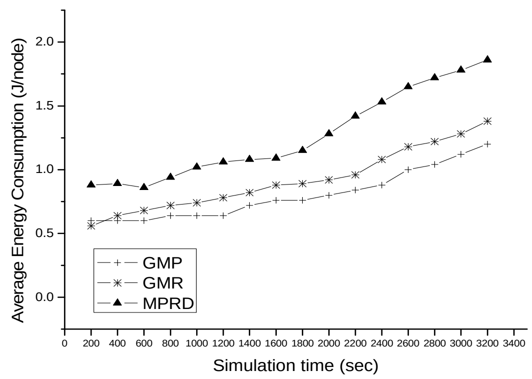

Figure 5: Energy consumption on the simulation time.

Figure 5 shows total energy consumption on the simulation time. Since three multicast protocols has no signaling overhead, energy consumption is dependent on total hop counts for data dissemination. Total tree length of MPRD is little longer than that of GMP and GMR in order to make each path shorter than the critical distance. Since the distance packet travels is proportional to the hop count as mentioned above, the total number of packet transmission in MPRD is more than that in GMP and GMR. Therefore total energy consumption of MPRD is little higher than GMP and GMR.

4 CONCLUSIONS

We propose a new multicast protocol for real-time data dissemination in wireless sensor networks. To deliver data to multiple destinations with real-time constraint, MPRD utilizes the property that data delivery delay is dependent on the distance a packet travels in wireless sensor networks. We refer to linear distance between the source node and the furthest destination as a critical distance. MPRD constructs multicast tree that every delivery distance from the source to each destination on the multicast tree is shorter than the critical distance and apply the spatiotemporal approach. Simulation results show that MPRD has better performance than traditional multicast protocols in terms of real-time data dissemination.

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