I2MTC 2008 – IEEE International Instrumentation and
Measurement Technology Conference
Victoria, Vancouver Island, Canada, May 12–15, 2008

M-IAR: Biologically Inspired Routing Protocol for Wireless Multimedia Sensor Networks

Md. Abdur Rahman[1], Reza GhasemAghaei[1], Abdulmotaleb El Saddik[1], Wail Gueaieb[2]
[1]Multimedia Communications Research Laboratory (MCRLab)
[2]Machine Intelligence, Robotics, and Mechatronics (MIRAM) Laboratory
School of Information Technology and Engineering
University of Ottawa, K1N6N5
{rahman, reza, abed}@mcrlab.uottawa.ca, wgueaieb@site.uottawa.ca

Abstract *– In this paper, we propose Multimedia-enabled Improved Adaptive Routing (M-IAR) that is optimized for single-source-to-single-destination multimedia sensory data traffic. It is an extension of the Improved Adaptive Routing (IAR) algorithm presented in our earlier work [1], in response to the increasing number of applications incorporating wireless multimedia sensors such as wireless microphones and cameras. M-IAR is a swarm-intelligent-based algorithm exploiting the concept of Ant Colony Optimization to optimize end-to-end delay, jitter, latency, energy consumption, packet survival rate, and routing path, within the multimedia wireless sensor network. The presented algorithm is proven to satisfy its goals through a series of computer simulations.*

Keywords *– ant routing, multimedia sensors, wireless sensor network.*

I. INTRODUCTION

Because of their attractive features, wireless sensor networks (WSNs) are now finding their presence in many applications such as covert military applications, remote surveillance of patients, elderly people, objects of interest, and sophisticated facilities, environmental monitoring and many others. First-generation sensor nodes used to be very simple and mostly consisted of static sensory data. However, with the emergence of complex second-generation multimedia sensors capable of delivering multi-modal sensory information, existing routing protocols seem to show poor performance. Multimedia sensory data poses several unique challenges on the routing protocols of these systems such as real-time delivery, tolerable end-to-end delay, proper bandwidth, jitter, and frame loss rate. Although many routing protocols have addressed multimedia traffic routing over Internet and Mobile Adhoc NETwork [2], [3], [4], [5], only very few attempts have addressed the problem of multimedia data routing over resource constrained WSNs. The multi-hop nature of most WSN applications is the main source of these challenges. The example of multimedia traffic over a WSN might be forwarding images, video, and audio data to a sink node.

As the size of the network scales up, routing becomes more challenging and critical. Lately, biologically-inspired intelligent algorithms have been deployed to tackle this problem [1], [2], [6], [7], [8], [9], [10], [11]. Ant routing has shown excellent performance in solving routing problems in WSNs [1], [3], [6], [11], [12], [13], [14], [15]. Routing techniques based on ant intelligence are inspired by the biological phenomenon that helps the ant in finding the shortest path among the explored routes and attracts more ants to reinforce the shortest path. In our earlier effort, we designed an ant colony based routing algorithm, called Improved Adaptive Routing (IAR) [1] that was specifically tailored to optimize several metrics of WSN including energy consumption, latency, throughput, and packet survival rate.

In this paper we extend IAR by incorporating two extra multimedia QoS parameters, namely the end-to-end delay and jitter. Authors in [5] have concluded that if QoS routing includes at least two additive metrics (such as delay, jitter, cost, and hop count) or a combination of additive and multiplicative metrics (such as reliability), then the routing problem becomes NP-complete, which is the case for the algorithm proposed herein, M-IAR.

The rest of the paper is organized as follows: In Section 2, we briefly review some closely related works. We describe the proposed protocol in Section 3. After that, M-IAR is tested through a series of computer simulations presented in Section 4. We conclude the paper with a few remarks and probable future extensions in Section 5.

II. RELATED WORK

Authors in [17] proposed a mobile swarm-based routing protocol for large scale WSN. The mobile swarm nodes have higher capacity in terms of longer communication range, high quality multimedia sensory data processing capability, mobility management, and better energy storage. The protocol defines three types of communication patterns: sensor nodes to swarm nodes, swarm to swarm nodes and swarm nodes to the sink. Regular sensor nodes detect the events and report to the nearest swarm node(s) and the mobile swarm nodes relocate them nearest to the event hotspot to capture detailed multi-modal information about the event for more accuracy. The routing protocol maintains a hierarchy of clusters and uses two types of routing table: one for intra-cluster routing and the other for inter-cluster routing. The protocol is intended for upstream routing and uses only dedicated high bandwidth backbone channel to communicate with the sink and avoid congestion. The protocol did not evaluate multimedia metrics such as bandwidth, packet loss ratio, jitter, and end-to-end delay. Also it does not actually employ the ant-based routing phenomena.

A swarm-intelligence-based multi-hop routing protocol for WSN is presented in [7]. The protocol uses swarm intelligence to route upstream traffic in the presence of topology changes due to node failures. It supports fault tolerance, and self-organization without any need for global route information. Each sensor node defines forwarding attitude, which depends on the closeness and remaining energy level, based on which the next-hop forwarding candidate is selected. Thus a pheromone gradient is formed, where sink has the highest pheromone and decreases the gradient toward the downstream nodes. In other words, the closer a node to the sink, the higher its pheromone level. Each node maintains the pheromone level of itself and its neighbors into the routing table and chooses the node with the highest pheromone level as the next-hop forwarding node and converges toward the highest pheromone owner i.e. the sink. However, the protocol might not be suitable for multimedia traffic.

A multi-path routing protocol based on swarm intelligence intended for mobile ad-hoc networks (MANET) is proposed in [2]. The protocol is specialized in carrying multimedia real-time traffic over the MANET. To provide higher bandwidth and higher delivery guarantee, it uses multi-path. It also supports high mobility of nodes and some QoS parameters. Each node maintains a routing table that contains information about its neighbors through local broadcasting. The source node first generates a forward ant that propagates toward the destination node and at each intermediate node some routing information is stacked such as available bandwidth of the link, number of visited nodes, the IP of each node etc. When the forward ant reaches the destination, it generates a backward ant, destroys itself, and the backward ant retraces the same path to make sure that the path is still efficient or active. However, the forward ants are forwarded to a next-hop neighbor with equal probability, while the backward ants adjust the probability based on the available bandwidth, delay and other factors. When the actual data is propagated, a node chooses the next-hop neighbor that has the highest priority i.e. probability value set by the backward ants. To handle multimedia traffic, the protocol chooses a multi-path routing paradigm and instead of choosing the neighbor with the highest probability as a next-hop node, it chooses a set of neighbor nodes according to their decreasing probability level to maintain required throughput at the sink. However, the protocol uses the concept of IP-based routing and needs modification to be suitable for WSN. The equal probability distribution of forward ants at each intermediate node might make the protocol less suitable for WSN.

A general overview of multimedia communication over WSN can be found in [18]. Although not specifically designed for WSN, an ant colony based QoS routing algorithm for carrying multimedia data is proposed in [3]. The algorithm uses delay, packet loss rate, jitter, link cost, bandwidth, and link delay metrics to find reinforcement value that enforces an ant to follow the best route. Another ant colony based routing algorithm to provide multimedia QoS support including bandwidth, loss rate, delay, and jitter is explored in [4]. However, the protocol does not target WSN and needs optimization to support WSN. A novel co-operative caching technique is designed by the authors of [19] for multimedia streaming over WSN, which can be used along with routing protocols to minimize the overhead of re-transmitting the lost packet that is already in cache.

III. PROTOCOL OVERVIEW

The proposed protocol works in an adaptive manner. We use the notion of location based convergence with the ant-based intelligence so that next-hop selection process converges toward the destination very fast. The protocol does not need to maintain the global state of the sensor nodes. All the sensor nodes take the routing decision based on their neighborhood information only. This makes M-IAR scalable and robust. The novelty of the proposed protocol is that we not only consider the closeness of next-hop neighbors toward the sink but also take into account the nearness of the neighbors from the sender node. It finds the shortest path rapidly by visiting least number of nodes. This eases the route discovery process. Multimedia applications can greatly benefit from this shortest path-based routing protocol because it results in low end-to-end delay and low jitter. Another very attractive feature of the protocol is that it piggybacks end-to-end acknowledgment packet to guarantee the delivery of every packet. Using M-IAR, any particular application may enforce the acknowledgment of any number of particular packets so that the sender can re-send those packets later on, if needed. This is particularly a very useful feature for multimedia streams. For example, if the application detects that an I-frame of a video stream did not reach the destination within a pre-defined duration time, the sender can re-send it later on.

In M-IAR, we modify the notion of delay factor assumed in IAR [1]. IAR assumed that the inter-hop communication delay is negligible compared to the local packet processing delay within a node and this local processing delay is equal throughout the WSN. Thus, delay was assumed to be proportional to the number of visited nodes. This is a flawed assumption for the case of multimedia traffic, because multimedia traffic is sensitive to both local processing delay as well as the transmission delay. In M-IAR we assume that both the number of nodes and the distance between any two of them have impact on the resulting end-to-end delay and jitter.

M-IAR is a flat multi-hop routing protocol, which exploits the geographic location of the sensor nodes in deciding the best possible route. The basic idea of M-IAR is to find the shortest route containing the least number of nodes between the sender and receiver node. We believe that multimedia processing is costly for the resource constrained sensor nodes in addition to the wireless communication cost. Thus, finding the shortest path with the least number of forwarding nodes will help us in achieving the least end-to-end delay and better jitter condition. Figure 1 shows the WSN spatial model that we use to evaluate the routing protocol.

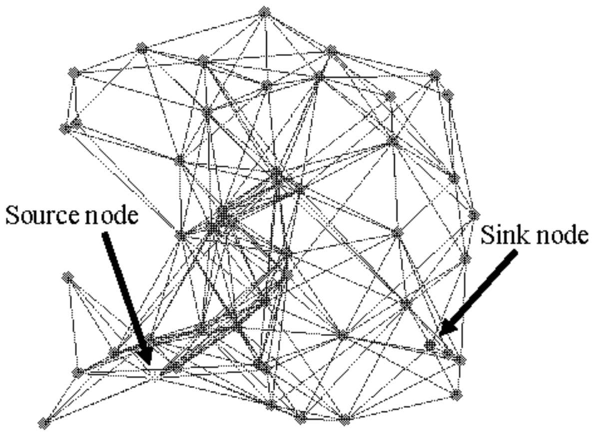

Fig. 1. M-IAR routing in WSN.

M-IAR uses the basic routing principles of IAR [1]. We assume that the sensor nodes have a limited range and each sensor node is thus within the proximity of a limited number of neighbors. In M-IAR, a source node finds the best shortest route between the source and the sink node. In addition to finding the shortest path, the protocol adapts according to the network dynamics and provides improved success rate, high energy efficiency, and less latency. M-IAR assumes that each node knows its own position, the position of its neighbors and the position of the destination through available GPS positioning system that comes with the commercially available sensor nodes. For the rest of the paper, the following notations are adopted.

N = Total number of sensor nodes.
$|N_k|$ = Set of neighbors of node *k*.
$C_{k,i}$ = Correction factor for adapting the cost of routing between the current node *k* and the next-hop node *i*.
$A_{i,d}$ = Heuristic correction factor for adapting the cost of routing between the next-hop node *i* and the destination node *d*.
$D_{k,i}$ = Distance between the current node *k* and the next-hop node *i*.
$D_{i,d}$ = Distance between the next-hop node *i* and destination *d*. The distance D between two points is calculated using simple co-ordinate geometry.
λ = Coefficient factor for $A_{i,d}$, which has a value between 0 and 1.
γ = Coefficient factor, which has a value between 0 and 1.
β = Desirability of the correction factor $C_{k,i}$ with a value between 0 and 1.
$d^i_{k,d}$ = Distance between the current node *k* and the destination node *d* via the neighbor node *i*, which is ($D_{k,i} + D_{i,d}$).
$P_{i,d}$ = Probability of choosing the node *i* as the next-hop node by the current node *k* toward the sink/destination node *d*.

Before the actual sensory data routing starts, M-IAR uses two types of ants to find the shortest path along with other optimization factors discussed earlier. Each sensor node maintains a routing table where the number of rows is equal to the number of neighbor nodes (N_k) and the number of columns is equal to the total number of sensor nodes (N). M-IAR chooses the best next-hop neighbor based on the following probability distribution:

$$P'_{i,d} = A_{i,d} \times \frac{P_{i,d} + \beta \times C_{k,i}}{1 + \beta \times (|N| - 1)} \qquad (1)$$

where $$A_{i,d} = \frac{1}{\lambda \times D_{i,d}} \qquad (2)$$

M-IAR considers the effects of both the distance from the current node to the next-hop node ($C_{k,i}$) as well as the remaining distance from the next-hop node to the sink ($A_{i,d}$) in choosing the best neighbor. At first, the source node sends a forward ant (F_{ant}) that uses equation (1) to find the probabilities of each of its neighbor, updates the routing table and forwards the packet to the neighbor with highest probability value. The same procedure is followed by each intermediate node until the sink node is reached. While traveling toward the sink, each forward ant also carries some global parameters in its packet header such as details of visited nodes, corresponding probability values, total number of hops visited, distance between each link, and neighbors of the visited nodes. To make sure that the protocol is converging well, M-IAR kills the F_{ant} if it has already visited more than half of the total number of nodes, which means that the path has either loops or non-convergent. Upon successfully reaching the destination, the F_{ant} creates a backward ant (B_{ant}), hands over the global header information to the B_{ant} and destroys itself. Although the B_{ant} follows the same route followed by its parent F_{ant}, at every reverse-visited node, the B_{ant} updates the probability values to reinforce the visited node. To do this, B_{ant} increases the probability value of the currently visited node using equation (3) and decreases the probability values of its neighbor nodes using equation (4).

$$P_{i,d} = \frac{P_{i,d} + \Delta P}{1 + \Delta P} \qquad (3)$$

$$P_{i',d} = \frac{P_{i',d}}{1 + \Delta P}, \quad i' \in neighbors(k), i' \neq i \qquad (4)$$

where the change of probability $\Delta P = e^{-\gamma \times d^i_{k,d}}$ (5)

Algorithm 1 and algorithm 2 show the pseudo-code of the proposed M-IAR protocol for the F_{ant} and the B_{ant} respectively. B_{ant} does not need any local broadcast to find the probability because it simply uses the global parameters containing the probability and other contextual information supplied by its parent F_{ant}. This makes the B_{ant} save significant amount of resources such as bandwidth and energy, and helps in reaching the source node much faster.

Algorithm 1: The Proposed M-IAR Algorithm for Forward-Ant

```
Forward-Ant(source-node, current-node, destination-node)
begin
  Define equal initial probability P_{i,d} for each sensor node;
  if Less than half of the sensor nodes visited then
    Use eq.(1) to find prob. P'_{i,d} of choosing the best next-hop neighbor;
    Update the routing table;
    Calculate the delay;
    if selected neighbor visited then
      Choose another neighbor node;
    else
      Add current-node to forward-list;
    if destination is reached then
      Calculate the end-to-end delay;
      Calculate jitter;
      Create a new Backward-ant;
      Copy forward-list, delay and jitter parameters to backward-list;
  else
    Perish Forward-Ant;
end
```

Algorithm 2: The Proposed M-IAR Algorithm for Backward-Ant

```
Backward-Ant(source-node, current-node, destination-node)
begin
  if source is reached then
    Perish Backward-Ant;
  else
    for all neighbor nodes do
      if selected neighbor node visited by Forward-Ant then
        Use eq.(3) to update the probability;
      else
        Use eq.(4) to update the probability;
      Remove first item of Backward-list;
      Update the delay parameter;
    Move Backward-Ant to selected neighbor node;
end
```

M-IAR can be configured for both acknowledgment-based (similar to TCP) and non acknowledgment-based (similar to UDP) routing. To imitate the acknowledgment-based multimedia traffic, we do not transmit a new forward ant unless the resulting backward ant reinforces the path chosen by the forward ant and reports to the sender. This will make sure that the packet is successfully received by the sink node. It will also assist any transport layer protocol, if used, to enforce the reliability mechanism. On the other hand, M-IAR waits for the acknowledgment message from the B_{ant} for a certain period of time by default. After timeout, the source node sends a new F_{ant} assuming the earlier packet is lost. This feature is suitable for real-time multimedia application that tolerates some packet losses.

IV. TEST RESULTS

We use Java for simulating M-IAR on a Pentium-IV workstation. As a WSN testbed, we consider 49 randomly distributed sensor nodes with random connecting distances between neighboring nodes. The values of λ, γ, and β were set as 0.7, 0.5, and 0.1 respectively. Each node is assumed to have a 10-meter omni-directional transmission range. The simulation is repeated 500 times for the duration of 200 seconds each. The number of F_{ants} that can be sent out within this timeframe depends on the number of hops between the source and the destination. At the beginning of the simulation, the protocol assumes one of the 49 nodes as the sink node and the rest of the 48 nodes as possible source nodes. The simulation takes each node from the set of 48 nodes in turn as the source node and finds the shortest path between the sink and the source node. After each simulation, M-IAR provides all the shortest paths between each source and the sink, the end-to-end delay between them and the jitter values. One interesting feature of M-IAR is that in more than 98% of the test cases, it could successfully find the shortest path within the first three route discovery attempts by the forward ants. Figure 2 shows the resulting end-to-end delay.

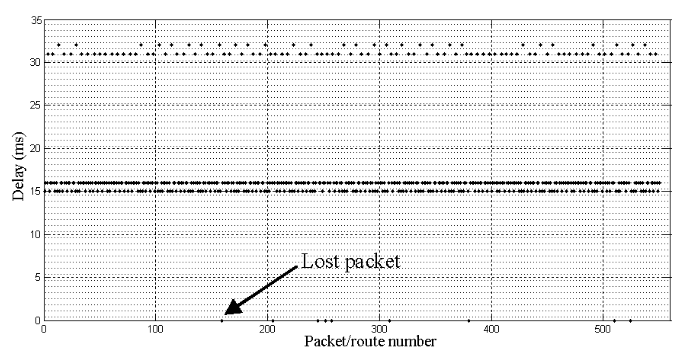

Fig. 2. End-to-end delay measurement.

The number of visited routes by the forward ants is related to the packet number. This is due to the fact that we calculate the end-to-end delay once a forward ant successfully reaches the destination through any route. In this context, the end-to-end delay is measured as:

End-to-end delay = Σ (local packet processing delay in each hop + transmission delay);

where local packet processing takes into account the delay in calculating the probabilities of next-hop neighbors, updating the routing table and the header information.

The total number of packets that were lost during the simulation time is 9 and shown as a delay value of zero (see Figure 2). This might happen in two cases. In the first case a packet is deemed non-convergent if it has already visited more than half of the sensor nodes and thus discarded. The second case might occur if the current node does not have any neighbor node within its range i.e. no way for exit. From figure 2 we find that the average end-to-end delay is 18.7 milliseconds, which shows that the protocol is capable of handling a throughput of 53 packets per second. Even the resource-constrained mobile devices tolerate an end-to-end latency of voice over IP packets up to 250 milliseconds and a jitter of 20 milliseconds. Some researchers argue that the tolerable end-to-end delay and jitter for video packets is even larger than the audio data, which might be subjective [16]. We thus believe that M-IAR will be capable of providing continuous multimedia stream within the tolerable delay bound. As found in Figure 2, the central tendency of end-to-end delay in M-IAR is around 15 to 16 milliseconds, while the highest end-to-end delay experienced was 32 milliseconds and the lowest was 15 milliseconds. We also observe that the end-to-end delay follows a pattern. For example, most of the delay values lie within the 15 to 16 milliseconds and 30 to 32 milliseconds range.

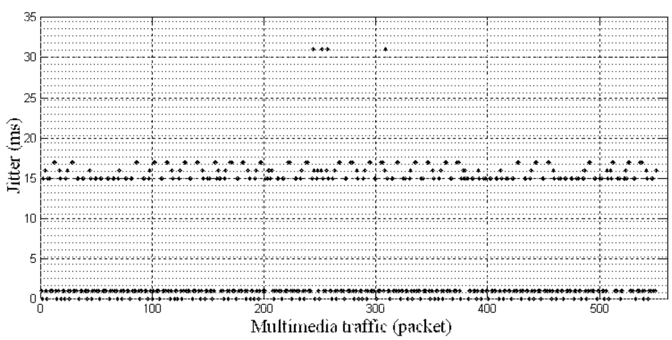

Fig. 3. Evaluation of M-IAR for jitter.

The effect of jitter is shown in Figure 3. We measure jitter by calculating the delay variance between two successively received forward ants at the destination node. The highest frequency of jitter value is between 0 and 1 millisecond while some sporadic jitter values are seen around 15 to 18 milliseconds band. Thus, we can conclude that the jitter distribution experienced by M-IAR is well capable of maintaining basic multimedia sensory data throughput at the sink.

V. CONCLUSION AND FUTURE WORK

In this paper we proposed an ant-colony based routing protocol that is specifically tailored for delivering multimedia packets over WSN. M-IAR is optimized for tolerable end-to-end delay and jitter to be able to handle multimedia sensory data. While routing multimedia traffic, it finds the shortest path by consuming less energy, visiting less number of hops, and providing high packet success rate. M-IAR can be configured for both upstream and downstream multimedia sensory data routing.

For future work, we plan to modify M-IAR for routing many-to-one multimedia sensory data. Another interesting feature we want to investigate is to incorporate the effect of dynamic network topology on the routing protocol as a result of node mobility or node failure.

REFERENCES

[1] R. GhasemAghaei, M. A. Rahman, W. Gueaieb, and A. El Saddik, “Ant Colony-Based Reinforcement Learning Algorithm for Routing in Wireless Sensor Networks,” *IEEE Instrumentation and Measurement Technology Conference 2007*, pp. 2173-2178, Warsaw, Poland, May 2007.

[2] S. Ziane and A. Mellouk, “A Swarm Intelligent Multi-path Routing for Multimedia Traffic over Mobile Ad hoc Networks,” *Q2SWinet’05*, Montreal, Quebec, Canada, Oct. 2005.

[3] J. S. Oh, S. Bae, J. Ahn, and S. Kang, “Route Reinforcement for Efficient QoS Routing Based on Ant Algorithm,” *International Conference ICOIN’04*, Busan, Korea, Feb. 2004.

[4] Z. Subing and L. Zemin, “A QoS Routing Algorithm Based on Ant Algorithm,” *IEEE International Conference on Communications*, Vol. 5, pp.11-14, Jun. 2001.

[5] Z. Wang and J. Crowcroft, “Quality-of-service routing for supporting multimedia applications,” *IEEE Journal on Selected Areas in Communications*, Vol. 14, No. 7, Sep. 1996.

[6] G. D. Caro, and M. Dorigo, “AntNet: Distributed Stigmergetic Control for Communications Networks,” *Journal of Artificial Intelligence Research*, Vol. 9, pp. 317-365, Dec. 1998.

[7] M. Paone, L. Paladina, D. Bruneo and A. Puliafito, “A Swarm-based Routing Protocol for Wireless Sensor Networks,” *Sixth IEEE International Symposium on Network Computing and Applications*, NCA’07, Jul. 2007.

[8] C. Shen and C. Jaikaeo, “Ad Hoc Multicast Routing Algorithm with Swarm Intelligence,” *Journal of Mobile Networks and Applications*, Vol. 10, pp. 47–59, 2005.

[9] E. Bonabeau, M. Dorigo, and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, 1999.

[10] I. Kassabalidis, M. A. El-Sharkawi, R. J. Marks II, P. Arabshahi and A. A. Gray, “Swarm Intelligence for routing in communication networks,” *IEEE Global Telecommunications Conference, GLOBECOM’01*, San Antonio, TX, USA, 2001.

[11] R. Muraleedharan and L. A. Osadciw, “A Predictive Sensor Network Using Ant System,” *In Proceedings of SPIE*, 2004.

[12] S. Selvakennedy, S. Sinnappan and Yi Shang, “T-ANT: A Nature-Inspired Data Gathering Protocol for Wireless Sensor Networks,” *J. Communications*, Vol. 1, No. 2, May 2006.

[13] Y. Lu, G. Zhao, and F. Su, “Adaptive Ant-based Dynamic Routing Algorithm,” *In Proceedings of the 5th World Congress on Intelligent Control and Automation*, pp. 2694-2697, Hangzhuo, China, Jun. 2004.

[14] Y. Zhang, L. D. Kuhn, and M. P. J. Fromherz, “Improvements on Ant Routing for Sensor Networks,” *International Workshop on Ant Colony Optimization and Swarm Intelligence*, Sep. 2004.

[15] D. Subramanian, P. Druschel, and J. Chen, “Ants and reinforcement learning: A case study in routing in dynamic networks,” *In Proceedings of IJCAI*, pp. 832-838, 1997.

[16] R. Steinmetz and C. Engler, “Human Perception of Media Synchronization,” *Technical Report 43.9310, IBM European Networking Center*, Heidelberg, Aug. 2001.

[17] M. Gerla and K. Xu, “Multimedia Streaming in Large-Scale Sensor Networks with Mobile Swarms,” *SIGMOD Record*, Vol. 32, No. 4, Dec. 2003.

[18] E. Gurses, O. B. Akan, “Multimedia Communication in Wireless Sensor Networks,” *Annals of Telecommunications*, Vol. 60, No. 7-8, pp. 799-827, Jul.-Aug. 2005.

[19] N. Dimokas, D. Katsaros, and Y. Manolopoulos, “Cooperative Caching in Wireless Multimedia Sensor Networks,” *Mobimedia'07*, Greece, 2007.