

Data Relevance Dynamic Routing Protocol for Wireless Visual Sensor Networks

Petros Spachos

Department of Electrical and Computer Engineering
University of Toronto
Toronto, ON, Canada
petros@comm.utoronto.ca

Dimitrios Hatzinakos

Department of Electrical and Computer Engineering
University of Toronto
Toronto, ON, Canada
dimitris@comm.utoronto.ca

Abstract—Survivability is crucial in Wireless Visual Sensor Networks (WVSNs) especially when they are used for monitoring and tracking applications with limited available resources. In this paper we are proposing the use of a data relevance dynamic routing protocol that tries to keep a balance between the energy consumption and the packet delay in a WVSN. The proposed dynamic routing protocol follows opportunistic routing approaches. The next node selection criterion can change the routing path dynamically following the network conditions and the channel availability while the energy consumption per node is also considered. Simulation results are presented that show an increase in network lifetime of up to 30% compared with traditional routing while the overall packet delay remains similar.

Index Terms—wireless visual sensor networks; opportunistic routing; dynamic routing;

I. INTRODUCTION

In recent years, there has been a lot of interest in building and deploying Wireless Visual Sensor Networks (WVSNs). WVSNs are composed of resource-constrained self-organizing wireless nodes where some of them or all of them are endowed with a low-power camera for a series of innovative multimedia sensing functions[1]. Visual information retrieved from those networks can significantly enhance the capabilities of surveillance and monitoring applications[2].

There is a plethora of applications such as event monitoring and tracking, where low-cost and easily deployed WSNs combined with visual sensors is the ideal solution. Inch scale sensor devices have been designed to work unattended with limited power requirements, for long periods of time. One of the looming challenges that threaten successful deployment of these networks is energy efficiency. Inch scale sensor devices have been designed to work with limited power requirements and computational capabilities. Compared to portable devices, such as cellular phones and laptops, where batteries can be recharged frequently, sensor node battery recharging or replacement is sometimes infeasible or impossible. The lifetime of any individual node, and as a consequence, of the whole network, is decided by how the limited amount of energy is utilized.

On the other hand, the packet delay is crucial to the success of these ubiquitous networks, especially in monitoring application. Network should provide high performance in

terms of factors such as packet delay with a network resource optimization plan. Trying to network a large number of low-cost and low power sensor nodes is a challenging problem. Routing and addressing are the primary issues to be tackled at the network layer. In this work, we will focus on the routing problem and especially on dynamic routing with use of opportunistic routing principles.

A data relevance dynamic routing protocol is proposed in this paper in order to fill the gaps between the packet routing and energy efficiency of a WVSN with delay constrains. The introduced protocol tries to combine the packet delay that can be delivered from a dynamic routing protocol based on a prioritize mechanism for different packets with the energy efficiency that can be guaranteed from an energy aware opportunistic routing protocol (EAOR), [3]. The protocol ensures that the network connectivity is maintained, the energy consumption of each sensor node in the network is at a similar level and the network performance in terms of delay is guaranteed. In contrast with traditional routing protocol and EAOR, the introduced protocol combines location and packet information to choose the next relay node.

The rest of this paper is organized as follows: The related works are reviewed in Section II. The system model is described in Section III followed by a description of the proposed routing protocol in Section IV. The performance evaluation and simulation results are presented in Section V. Conclusions are summarized in Section VI.

II. RELATED WORK

Opportunistic routing has attracted much attention as it is considered a promising direction for improving the performance of wireless ad hoc and sensor networks [4]. It tries to take advantage of broadcast characteristics of wireless transmission. The path can change dynamically, following the network conditions, making it suitable for cognitive radio networks with fast variation of spectrum availability. The idea of opportunistic routing has been introduced in [5]. *Extremely Opportunistic Routing (ExOR)*, allows the routers to use multi-path routes toward the destination. Every link between a transmitter and a receiver has a priority level according to the *Expected Transmission count (ETX)* metric, which is based on the distance between the receiver and the destination. The

shortest the distance, the highest the priority. The receiver with the highest priority will be selected as the next relay node. ExOR ties the MAC with routing, imposing a strict schedule on routers access to the medium. *MAC-independent Opportunistic Routing and Encoding Protocol (MORE)* [6] tries to enhance ExOR. MORE provides opportunistic routing by a network coding approach extended to multicast. It also uses the concept of innovative packets in order to avoid duplicate packets which might occur in ExOR.

A spectrum aware routing is proposed in [7]. *Spectrum Aware Mesh Routing (SAMER)*, opportunistically routes traffic across paths with higher spectrum availability and quality. SAMER tries to balance between long-term route stability and short-term opportunistic performance. In [8] a *Spectrum Aware Opportunistic Routing (SAOR)* algorithm is introduced. SAOR uses an *Opportunistic Link Transmission (OLT)* metric, which is a combination of transmission delay, packet queuing delay and link access delay. By introducing channel access probability to characterize the opportunistic CR link, *Multi-channel Spectrum Aware Opportunistic Routing (MSAOR)*, [9], improves the performance of SAOR in a three-node network.

In this paper, we propose an opportunistic routing protocol with opportunistic spectrum access for WSNs. A selection criterion is proposed, that has been designed by taking into consideration the limited energy resources and computational capabilities of sensor nodes. A simple network address mechanism is used in order to obtain the selection criterion. To make the link model more practical, a packet error rate has been assigned over each available link while a collision avoidance scheme that prevents collisions by making use of the cognitive radio is applied. The proposed scheme is evaluated through a large scale sensor network via a discrete event simulator and is compared with three other routing schemes.

III. SYSTEM MODEL

In this section, an overview of the basic functionality of the system model is provided.

A. Network Address

Each sensor node should have a unique network address. Since the proposed protocol is based on location information about the nodes, the network address mechanism is related to the distance between a node and the destination. When the network address of node i is given and the network address of the destination node d is known, a delivery criterion $c_{i,d}$ should be locally obtained. This delivery criterion is correlated with the distance between the two nodes.

During an initialization phase, the destination node can broadcast a number of identity advertisements packets. When a node receives a packet, it can count the smallest number of hops toward the destination and use it as the delivery criterion. When all the nodes have broadcast all the packets, every node in the network knows its delivery criterion.

When a new node joins the network, it can obtain its logic address by acquiring the logic address of its neighbor nodes. When a node leaves the network or there is a different source

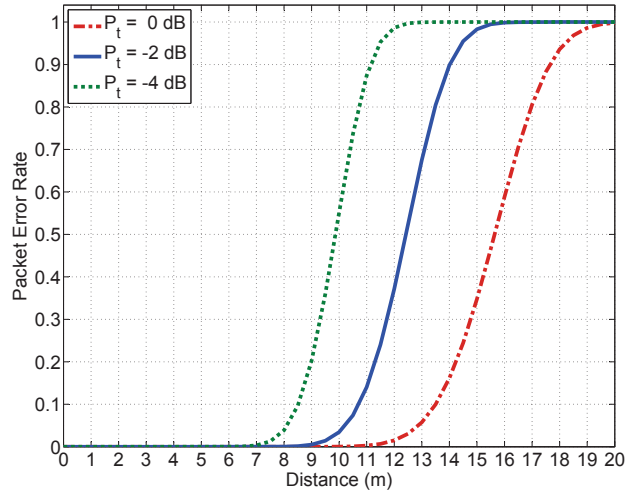


Fig. 1. Packet error probability curve for BPSK without channel coding for three different transmission power values.

node, the network addresses of all the nodes remains the same. Only if the destination node changes the procedure should take place again. This address scheme was followed because in a WWSN there can be multiple source while the destination, which is usually a control room, does not change.

B. Link Model

Link model follows a similar approach with [10]. When a node sends a packet to a neighbor node over a link there is a Packet Error Rate (PER). To simulate a realistic channel model for lossy WWSNs with Binary phase-shift keying (BPSK) without channel coding, the $PER(i)$, can be written as [11],

$$P\hat{E}R(i) = 1 - \left(1 - Q\left(\sqrt{\frac{2P_t(i) \cdot \hat{G}(i)}{\sigma_n^2}}\right)\right)^{F_d}, \quad (1)$$

where P_t is the transmission power, F_d is the length of the data, σ_n^2 is the noise power, $Q(x) = \frac{1}{\sqrt{\pi}} \cdot \int_{\frac{x}{\sqrt{2}}}^{\infty} e^{-t^2} dt$ and

$$\hat{G}(i) = A \cdot \hat{D}_s(i)^{-n}, \quad (2)$$

where A is a constant, $\hat{D}_s(i)$ is the distance between the sender node s and the next node i , and n is wireless channel path loss component.

Every packet transmission process is subjected to PER . The PER function under three different P_t can be seen in Figure 1. It can be inferred that P_t is not only important for the total energy consumption of the network but also for the network connectivity. A high P_t can lead to waste of the limited energy of the nodes, while increasing the collisions between neighbor nodes. A low P_t can decrease network connectivity, hence, more nodes are needed to monitor an area. In the proposed protocol, the P_t was carefully selected following the requirements of the monitoring area.

C. Collision Avoidance

We make use of the cognitive radio to prevent collisions, [12], [10]. The radio can have access to a group of data channels. Each group is associated with two different frequency

tones, one for sensing and one for polling which are also distinctive from the data channel frequency. Therefore, the radio hardware should be composed of two transceivers, one for sensing/polling and one for data.

Initially, when a node has to transmit a packet, it senses for an available channel and then broadcasts a polling tone. All the nodes which are in the range of the transmitter node, they can detect this polling tone. A neighbor node can decide to join the transmission based on its own autonomous availability. If a node decides to join the transmission it sends out a polling tone to its surrounding nodes. In this way, sensing and polling tones protect wireless link module from spectrum interference.

D. Relevance Level Scheme

The relevance level scheme that is followed is crucial for the performance of the proposed protocol. A relevance level scheme similar to [13], is used. When the source node forms a packet for an event that triggered the visual sensor, the packet will have a field with the relevance level of the event. This field will help the relay nodes that will participate in the packet transmission, to understand the importance of the packet.

A packet with a low relevance level, will be transmitted through nodes that are close to the transmitter, since the time delay is not crucial for this packet. For instance, nodes can exchange location information in a cluster of the monitoring area, when there is no event taking place. These packets should be finally forwarded to the destination node to update the records for the location and the number of the nodes in the network. The location packets can be delivered to the destination node periodically, when there is no traffic in the network and through nodes that have not participate in many packet transmissions. These nodes have higher energy level. Location packets are marked with relevance level $L_k = 0$.

A packet with a high relevance level, needs to be delivered to the destination node with the minimum delay. In this case, nodes that can deliver the packet with the less number of hops, under the channel conditions and the nodes availability at the time of the transmission will be used. If any other packet with smaller relevance level is taking place at the same time, the packet with the smaller relevance level will have to wait. The packets inside the buffer of the nodes are prioritized based on their relevance level. The higher the level, the higher the priority.

Table I shows the 5 relevance levels that are followed for the packet transmission in the proposed dynamic routing protocol.

IV. DATA RELEVANCE DYNAMIC ROUTING

The proposed *data relevance dynamic routing* for WVSNs is a *reactive opportunistic* routing protocol because it discovers routes only when desired. An explicit route discovery process is taken place only when is needed. In the introduced protocol, that process is *destination-initiated*. The destination node of the network begins the route discovery process and the process ends, when a routing path has been established while a maintenance procedure preserves it until the path is no longer available or desired.

| Level L_k | Relevance |
|-------------|--|
| 0 | Irrelevant. No information should be transmitted immediately |
| 1 | Low Relevance. The packet should be delivered to the destination. It can tolerate some delay. |
| 2 | Medium Relevance. The packet should be delivered to the destination through any path that can lead up to a certain delay. |
| 3 | High Relevance. The packet should be delivered to the destination through the path with the best delay at the transmission time. |
| 4 | Maximum Relevance. The packets should be delivered with minimum delay to the destination. Any other packet transmission will have to wait. |

TABLE I
VALUES FOR THE DIFFERENT RELEVANCE LEVELS

In this routing protocol, multiple paths between the source and the destination are maintained. Packets can follow any of those paths, according to the dynamic changes of the network conditions, such as interference, channel and relay node availability, as well as the energy levels of the relay node. Moreover, due to the probabilistic choice of the relay nodes, the protocol is able to evaluate different routing paths continuously and choose them according to the condition in every time slot.

The proposed protocol has the following two phases: *Initialization phase* and *packet transmission process*.

- 1) *Initialization phase*. The destination node creates a small packet in order to transmit it toward the source node. That packet has the delivery criterion field, $c_{dst,dst}$ equals to zero. Every sensor node i in the network knows its relative location, hence it can categorize the nodes around it into *neighbor node set* and *candidate node set*. Neighbor node set of node i is a set S_i of all the nodes in the transmission range of node i :

$$S_i = \{j \in N | d_{i,j} \leq R\}, i \neq j \quad (3)$$

where N is the set of all the nodes in the network, $d_{i,j}$ is the distance between node i and node j and R is the transmission range of the node. Candidate node set of node i is a set V_i of those nodes that are closer to the *destination node of the packet*, than the transmitting node. Candidate node set is a subset of neighbor node set, $V_i \leq S_i$. During the initialization phase, the destination node of the packet is the source node s , hence:

$$V_i = \{j \in S_i | d_{j,s} \leq d_{i,s}\}, i \neq j \quad (4)$$

The destination node initiates the connection by flooding the packet to its candidate node set toward the source node. Every intermediate node forwards the packet to its candidate node set, while increasing the delivery criterion field.

When the packet reaches the source node, the source node calculates the delivery cost to the destination

through different routes, estimates the energy required for transmission to the nodes at its candidate set and then drops the packet. After the end of the whole process, each sensor node in the network has all the necessary information to start transmitting data.

- 2) *Packet transmission process.* Packet transmission begins right after the initialization phase. There are four types of packets: DATA, acknowledgement (ACK), Request To Send (RTS) and Clear To Send (CTS). Every packet transmission is subjected to the PER, as in Eq.1.

When a node n has a packet to transmit, there is a RTS/CTS handshake between the transmitter and the nodes at its candidate set. The transmitter search for an available channel C_i , floods a RTS packet over that channel and waits till the first response. The transmitter will wait for the response at the same channel C_i . Depending on the network conditions and the distance between the transmitter and the candidate node, as in Eq.1, some of the nodes in the candidate set will receive the RTS.

On the reception of a RTS packet, node k will response with a CTS to node n , if it is available for immediate packet transmission and there is no other packets waiting to be transmitted. Before the transmission of the CTS packet, node k will wait for time:

$$T_{backoff} = ((\bar{L} - L_k) \times \log(d)) \times C_0 + C_1 \times SIFS, \quad (5)$$

where \bar{L} is the mean of the Relevance Level Scheme that is applied, L_k is the Relevance Level k of the current packet, d is the distance between the communicating nodes, $SIFS$ is the Short Interframe Space and C_0 and C_1 are constants.

Figure 2 shows an example of the $T_{backoff}$ under different distances between the communication nodes and for packets with different Relevance Levels.

After that time, node k will check if channel C_i is available in order to response with a CTS *over the same channel* as the RTS. If the channel is unavailable, it will wait. Since the CTS transmission is also subjected to the PER, there might be some packet losses. On successful reception of a CTS packet, transmitter will forward the DATA packet to the node that replied first with a CTS and will ignore any the consequent CTS packets for the same DATA packet. The transmission will take place *over the same channel* as the RTS/CTS handshake and the transmitter will wait for an ACK of the packet.

As it can be inferred from Eq.5, the selection criterion of the next relay node is a combination of the distance from the destination and the relevance level of the packet. As the relevance level of the packet decreased, the closer a node is to the transmitter the smaller the $T_{backoff}$. Hence, neighbor nodes that are close to the transmitter will serve packets with low relevance level. These nodes will require more hops to deliver the packets to the desti-

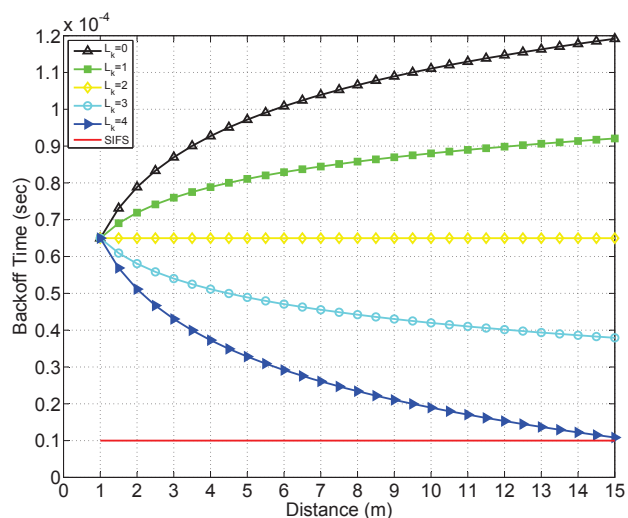


Fig. 2. Backoff time for nodes in different distances from the transmitter and for packets with different relevance level values, L_k , following Eq.5 for $C_0 = 10^{-5}$ and $C_1 = 7$.

nation. If a packet with a higher relevance level needs to be transmitted through the same nodes, the nodes will store all the packets in their buffer and will prioritize their transmission according to their relevance level. The higher the relevance, the higher the transmission priority. On the other hand, packet with high relevance level will be served by nodes that are placed close to the transmission range of the transmitter. These nodes will forward the packets to the destination in less number of hops than any other available node at the time. If a packet with lower relevance level needs to be transmitted through the same nodes, that packet will have to wait for any other packet with higher relevance level to be transmitted first.

Each intermediate node follows the same packet transmission process. Consequent packet transmissions might use different paths and different channels. This process continues till all the packets reach the destination node.

V. PERFORMANCE EVALUATION AND SIMULATION RESULTS

In this section, we compare the proposed protocol with traditional routing in terms of network life time, energy distribution and average end-to-end delay. Traditional routing is always using nodes that can deliver the packet in the less number of hops and over reliable links, i.e. links with $PER < 10\%$. On the other hand, the proposed dynamic opportunistic routing tends to use links with $PER < 80\%$. Dynamic routing checks the link performance and availability for every packet transmission with traditional routing has a pre-fixed path for all the transmissions.

The discrete event simulation system, OMNeT++ [14], was used for simulations. The sensor nodes were uniformly randomly distributed over a $100 \times 100(m^2)$ network field. The communication parameters were chosen based on IEEE 802.15.4. All the simulation parameters are listed in Table II.

| Parameter | Unit | Value |
|------------------------------|---------|----------------|
| Length of the data (L_f) | bit | 100×8 |
| RTS/CTS/ACK packet | bit | 8×8 |
| SIFS | μs | 10 |
| Transmission Range(R) | m | 10 |
| TransmittingPower (P_t) | mW | 15 |
| TransmissionRate | kbps | 250 |
| C_0 | | 10^{-5} |
| C_1 | | 7 |

TABLE II
SIMULATION PARAMETERS

A. Network Lifetime

Network lifetime is defined as the interval between the beginning of a packet transmission of the network time until the first node failure due to battery depletion. Under the assumption that the sensor nodes operating on a pair of AA batteries with 1000mAh capacity, each sensor node will have an initial energy of:

$$E_{init} (J) = capacity(Ah) \times voltage(V) \times time(s) \quad (6)$$

$$= 1 \times 2 \times 1.5 \times (60 \times 60) = 10800J$$

Figure 3 shows the results. Traditional routing forward all the packets toward the destination through the same routing path. Following this routing approach, these nodes will keep transmitting all the packets and eventually they will run out of energy.

On the other hand, the proposed Data Relevance (DR) dynamic routing protocol tries to discover paths that consists of sensor nodes that are closer to the destination only for packets with high relevance level. The location of the next node is important but the relevance level of the packet is

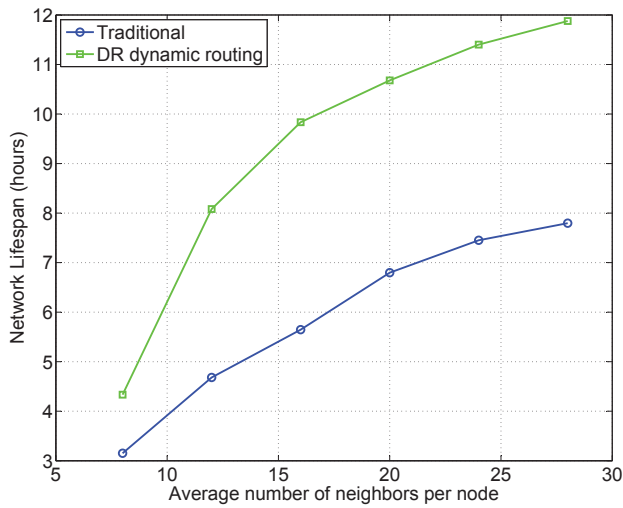
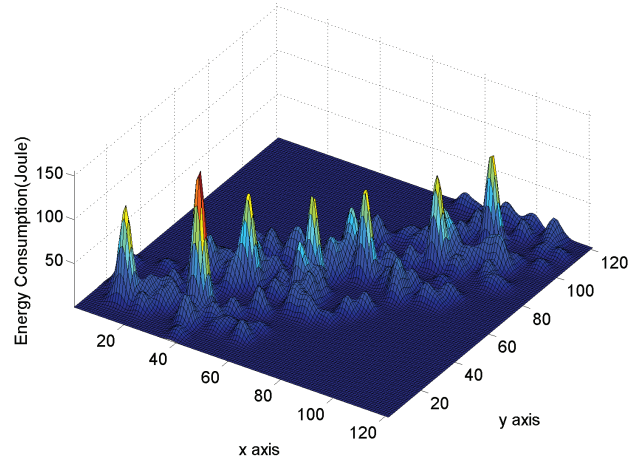
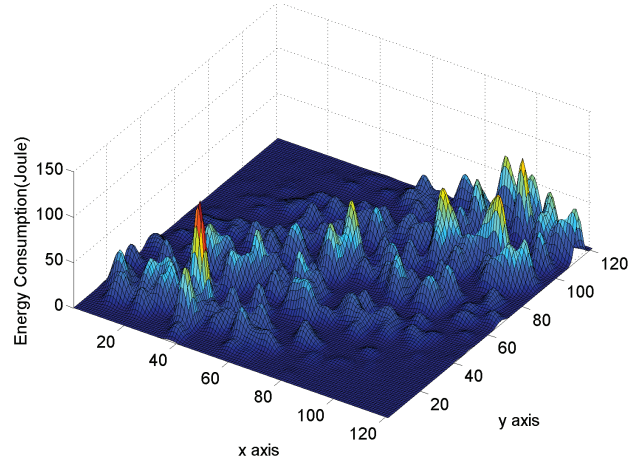


Fig. 3. Network lifetime under different network density.



(a) Traditional Routing.



(b) DR dynamic routing.

Fig. 4. Distribution of energy consumption in the network.

also crucial. Nodes that have not participated in many packet transmissions are preferred for packets with low relevance level while nodes that are on the best path are preferred for the transmission of crucial packets. For crucial packets as long as there are neighbor nodes in great distances with sufficient energy levels, these nodes are preferred over nodes in comparable distances. In this way, network lifetime is higher than traditional. The nodes that are on the best path are not participate in every packet transmission and can conserve energy. Moreover, as the network density increased there are more neighbor nodes on the best path from the source toward the destination, extending the network lifetime.

B. Energy Distribution

Energy distribution is used to illustrate the energy consumption of each node in the network. The network consist of 300 nodes, uniformly and randomly distributed.

Figure 4 shows the energy distribution for the two protocols. Traditional routing keeps using almost the same nodes after a number of packet transmissions, while there are nodes in the network that have not participate in any packet transmission. The energy distribution is better with data relevance protocol.

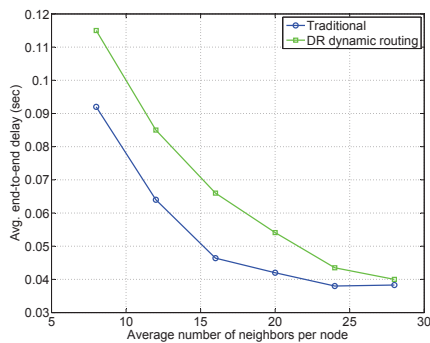


Fig. 5. End-to-end delay for packet with relevance level 0.

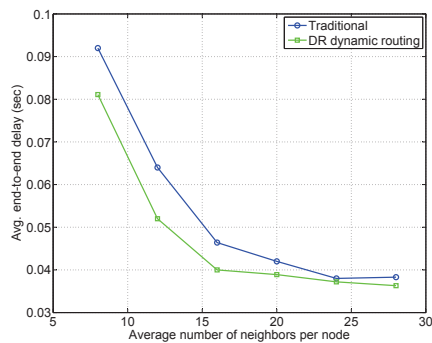


Fig. 6. End-to-end delay for packet with relevance level 2.

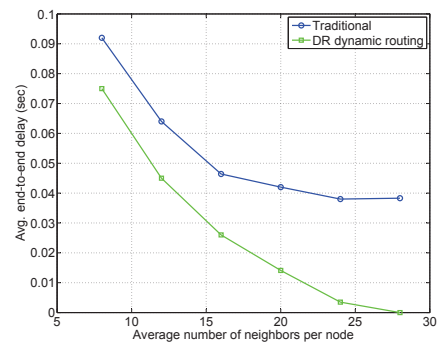


Fig. 7. End-to-end delay for packet with relevance level 4.

More sensor nodes are used for different packet transmissions. That approach tries to use almost all the available nodes at the network field for a more efficient routing scheme.

C. End-to-end delay

End-to-end delay is the time required for a packet from the source to reach the destination. In our simulation a number of 1000 packets with relevance levels 0, 2 and 4 were transmitted from the source to the destination for each network density and the average end-to-end delay was calculated. The results are shown in Figures 5,6 and 7.

Traditional routing has the same performance for every packet transmission. Data relevance dynamic routing does not perform as well as traditional routing for packets with low relevance level. The main reason is that this approach tries to conserve energy to transmit packets with higher relevance levels. Hence, it tends to use nodes that have not been used that often for packet transmission. These nodes lead to paths with more number of hops than traditional routing and as a consequence the average end-to-end packet delay is higher than traditional. As the network density increased, the difference between the two approaches is smaller. The main reason is that dynamic routing can discover more neighbor nodes that can lead to paths with similar performance as traditional routing.

For a medium relevance level packets, the performances of the two routing protocols are similar. Dynamic routing protocol tries to find any path toward the destination, not the best one, but it also uses in opportunistic nature. Hence, it can deliver the packets over nodes and links that traditional routing does not use. These links might be unreliable for traditional routing, while it can be reliable for the dynamic routing at the time of the transmission, leading to a path with less number of hops toward the destination. On average, the performance for these packets is similar.

For maximum relevance level packets, dynamic routing performs better than traditional. The reason is the opportunistic aspect of this protocol. It takes advantage of the broadcast nature of wireless communications and manage to deliver the packets over any available link at the time of the transmission. These links can deliver the packet in less time to the destination, leading to a significant smaller average end-to-end delay.

VI. CONCLUSION

In this paper, we are proposing a data relevance dynamic routing protocol for visual wireless sensor networks. The proposed protocol has a next relay node selection criterion that combines both location and packet information. It is shown through simulations that the protocol can extend the lifespan up to 30% while it can deliver better end-to-end delay than traditional routing for packets with high relevance level.

REFERENCES

- [1] Y. Charfi, N. Wakamiya, and M. Murata, "Challenging issues in visual sensor networks," *IEEE Wireless Communications*, vol. 16, no. 2, pp. 44–49, April 2009.
- [2] I.F. Akyildiz, T. Melodia, and K.R. Chowdury, "Wireless multimedia sensor networks: A survey," *Wireless Communications, IEEE*, vol. 14, no. 6, pp. 32–39, December 2007.
- [3] Petros Spachos, Periklis Chatzimisios, and Dimitrios Hatzinakos, "Energy aware opportunistic routing in wireless sensor networks," *IEEE GLOBECOM 2012*, Dec. 2012.
- [4] Haitao Liu, Baoxian Zhang, H. Mouftah, Xiaojun Shen, and Jian Ma, "Opportunistic routing for wireless ad hoc and sensor networks: Present and future directions," *Communications Magazine, IEEE*, vol. 47, no. 12, pp. 103–109, Dec. 2009.
- [5] Sanjit Biswas and Robert Morris, "Opportunistic routing in multi-hop wireless networks," *SIGCOMM Comput. Commun. Rev.*, vol. 34, no. 1, pp. 69–74, 2004.
- [6] Szymon Chachulski, Michael Jennings, Sachin Katti, and Dina Katabi, "Trading structure for randomness in wireless opportunistic routing," *SIGCOMM '07*, pp. 169–180, 2007.
- [7] Ioannis Pefkianakis, S.H.Y. Wong, and Songwu Lu, "Samer: Spectrum aware mesh routing in cognitive radio networks," in *IEEE DySPAN 2008*.
- [8] Shih-Chun Lin and Kwang-Cheng Chen, "Spectrum aware opportunistic routing in cognitive radio networks," *IEEE Global Telecommunications Conference (GLOBECOM 2010)*, pp. 1–6, Dec. 2010.
- [9] Changliang Zheng, E. Dutkiewicz, Ren Ping Liu, R. Vesilo, Gengfa Fang, and Zheng Zhou, "Opportunistic routing in multi-channel cognitive radio networks," *2011 ISCIT*, pp. 532–537, Oct. 2011.
- [10] Petros Spachos, Periklis Chatzimisios, and Dimitrios Hatzinakos, "Energy efficient cognitive unicast routing for wireless sensor networks," *IEEE VTC 2013*, Jun. 2013.
- [11] J.G. Proakis, *Digital Communication*, McGraw-Hill Inc., 1995.
- [12] Petros Spachos, Periklis Chatzimisios, and Dimitrios Hatzinakos, "Cognitive networking with opportunistic routing in wireless sensor networks," *IEEE ICC 2013*, Jun. 2013.
- [13] D.G. Costa, L.A. Guedes, F. Vasques, and P. Portugal, "A routing mechanism based on the sensing relevancies of source nodes for time-critical applications in visual sensor networks," *2012 IFIP Wireless Days*, pp. 1–6, Nov. 2012.
- [14] OMNeT++, "Network simulation framework," <http://www.omnetpp.org/>.