Applied Soft Computing 30 (2015) 104–112

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

# A multi-objective routing algorithm for Wireless Multimedia Sensor Networks

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ARTICLE INFO

*Article history:*
Received 8 May 2014
Received in revised form 22 January 2015
Accepted 22 January 2015
Available online 2 February 2015

*Keywords:*
Multi-objective optimization
Wireless Multimedia Sensor Networks
Strength Pareto Evolutionary Algorithm
Quality of Service

ABSTRACT

In this paper, a new multi-objective approach for the routing problem in Wireless Multimedia Sensor Networks (WMSNs) is proposed. It takes into account Quality of Service (QoS) requirements such as delay and the Expected Transmission Count (ETX). Classical approximations optimize a single objective or QoS parameter, not taking into account the conflicting nature of these parameters which leads to sub-optimal solutions. The case studies applying the proposed approach show clear improvements on the QoS routing solutions. For example, in terms of delay, the approximate mean improvement ratios obtained for scenarios 1 and 2 were of 15 and 28 times, respectively.



## 1. Introduction

Wireless sensor networks [1] are composed of small devices, called sensor nodes, which cooperate to forward collected data to a sink node that either uses the data locally or forwards it to other networks through a gateway, like for example, the Internet. Sensors are resource-limited devices composed of sensing, processing, transceiver, and power units.

The addition of low cost multimedia hardware to sensors fostered the development of Wireless Multimedia Sensor Networks [2], allowing the retrieval of multimedia streams, and/or scalar sensor data. Wireless sensor networks have many application areas [2] such as multimedia surveillance sensor networks, storage of potentially relevant activities, traffic avoidance, enforcement and control system, and many more.

Routing protocols [3] in WSNs can be classified according to the network structure, protocol operation, how routing information is acquired and maintained. In terms of network structure, routing protocols can be divided into flat-based routing, hierarchical-based routing and location-based routing. In flat-based routing, typically nodes have similar roles, whereas in hierarchical-based routing nodes have different roles. In location-based routing, location information is used to route data in the network. According to protocol operation, these protocols can be classified as multipath-based, query-based, negotiation-based, QoS-based, or coherent-based routing techniques. In multipath-based routing, multiple paths are maintained between a source-destination pair. In query-based routing, the destination node sends a query through the network and the node with this data, sends an answer. In negotiation-based routing, high level data descriptors are used to eliminate redundant data transmissions through negotiation. In QoS-based routing, certain QoS metrics have to be satisfied while routing data through the network. In coherent-based routing, sensors cooperate in processing data flooded throughout the network. According to how routing information is acquired and maintained, they can be classified into proactive, reactive, and hybrid. In proactive protocols, nodes compute routes before they are needed. In reactive protocols, nodes compute route on demand. Hybrid protocols combines ideas of both.

Multimedia applications have different QoS requirements such as, bounded latency or delay, throughput, jitter, availability, and energy consumption. Since energy efficiency is considered as the main goal of most WSNs routing protocols, the majority of these protocols does not perform well when applied to QoS-constrained WMSN. Routing techniques in WMSN can be classified similarly to those of WSNs. In [4] another categorization for WMSN routing protocols is presented. Protocols are classified based on the handled data types, data delivery model types, classes of algorithms adopted, and the used hole-bypassing approach.

Many routing schemes [4,5] have been proposed to address QoS requirements. In most of these schemes, only one of the desired objectives is optimized, while others are assumed as problems' constraints [6]. In certain applications, a meta-heuristic approach [7,8] using a multi-objective optimization (MO) algorithms that can provide several optimal solutions may be preferred, since single design objective algorithms ignore other relevant objectives. By considering all objectives simultaneously, a set of optimal solutions can be generated, also known as the Pareto solutions [9] of the multi-objective problem. It is also known from [10] that finding optimal routes for multiple objectives in networks (multi-constrained QoS routing), is a NP-complete problem, hence efficient heuristic search algorithms based on reduced-complexity Evolutionary Algorithms (EAs) [11] are necessary.

The Expected Transmission Count (ETX) [12] metric is an estimation of the expected total number of transmissions (including retransmissions) required to deliver a packet to the destination node successfully. ETX allows finding high throughput paths on a multi-hop wireless network, and incorporates the effects of link loss ratios, asymmetry in the loss ratios between the two directions of each link, and the interference among the successive links of a path.

This paper proposes a new multi-objective approach for the WMSN routing problem that takes into account QoS parameters such as delay and ETX. A comparison of the proposed approach with two alternative routing protocols was also presented.

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http://dx.doi.org/10.1016/j.asoc.2015.01.052
1568-4946/

The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 presents the WMSN routing problem formulation. Section 4 presents the multi-objective optimization concept, formulation and our Strength Pareto Evolutionary Algorithm (SPEA) implementation used to solve the problem. Sections 5 and 6 present the simulation model and results respectively. Finally, Section 7 presents conclusions and future work.

## 2. Related work

The Dynamic Source Routing (DSR) [13] protocol, one of the well known Mobile Ad-hoc Networks (MANETs) routing protocols, is a single path on-demand routing protocol. If a data packet has to be sent and no route to the destination is available, the source node starts a route discovery process by flooding Route REQuest (RREQ) packets targeting the destination node. Each neighbor receiving the RREQ packet checks if it is the destination. If so, it sends a Route REPly (RREP) packet back to the source after adding the accumulated routing information contained in the RREQ packet. The shortest returned path is the one used for routing.

The High Throughput Low Coupling Multipath extension to the Dynamic Source Routing (HTLC-MeDSR) [14] protocol is a multipath on-demand routing protocol. Similarly to DSR, a RREQ is issued only if a data packet has to be sent and no route to that destination exists. The destination also issues RREP packets to the received RREQ packets. HTLC-MeDSR uses probe packets to detect link failures and each node overhears other nodes packet transmissions to increase the False Routing Failures (FRFs) accuracy. HTLC-MeDSR uses ETX information to find high throughput paths, and the correlation factor to find paths with low coupling if they exist. The set of paths with the highest throughput and the small correlation factor are the ones used.

The authors of [15] proposed a multi-objective routing algorithm that identifies a set of Pareto optimal routes, which represent different trade-offs between energy consumption and communication latency, for both single and multipath routing problems. One of the reasons behind the selection of the objectives is that sensor nodes are powered by batteries which makes power conservation an important goal. By minimizing the number of hops in a path, communication latency can be minimized since in most situations, latency is a consequence of the number of intermediate nodes along a communication path. WSN and WMSN have different QoS requirements, as multimedia traffic generally requires a minimum bandwidth.

In [16], a performance comparison of two Multi-Objective Evolutionary Algorithms (MOEA), namely the Non-dominated Sorting based Genetic Algorithm-II (NSGA-II) and the Multi-Objective Differential Evolution (MODE) algorithm, is presented. MOEAs are used to find optimal routes between a source and a destination nodes taking into account conflicting objectives, like dissipated energy and end-to-end delay in a fully connected wireless network. Since sensors can be deployed over a vast area, fully connected networks were not considered in this study.

The closest work to ours was presented in [17]. The authors propose a QoS based multi-objective optimization algorithm aiming at ensuring certain QoS levels in Wireless Mesh Networks (WMN). Some of the QoS parameters optimized are bandwidth, packet loss rates, delay and power consumption. Our approach targets WMSN QoS requirements instead. The ETX metric is used since it allows finding high throughput paths taking into account link loss ratios, links' asymmetries, and interference among the successive links of a path. The authors in [14] have shown that low ETXs paths are also energy efficient. The selection of a link with a certain bandwidth does not guarantee that the path has a good throughput. Another difference was on the problem formulation presented. The authors of [17] presented a linear programming formulation, not making clear how the presented formulation is used by the multi-objective optimization algorithm. We modeled the routing problem as a multi-constrained QoS routing problem and consequently used multi-objective optimization algorithms to solve it. In addition, in [17], it was not clear how the MOEA algorithm was implemented. In contrast, we present and explain in detail how our MOEA algorithm was implemented, namely: (1) the population initialization process, (2) how genetic operators were used.

The authors of [18] proposed a multi-objective routing optimization approach that uses a real-valued genetic algorithm (RVGA), which obtain benefits of better convergence properties by maintaining an unconstrained Pareto archive without employing an independent search population, aiming at prolonging the average network lifetime. The proposed approach, whose objectives are to minimize the total energy consumption, and to maximize the time required for nodes to recharge or replace their batteries, accomplishes its goal by combining a $k$-shortest paths based search space pruning and an edge metric consisting of an association between a pair of nodes energy cost with its link. Energy efficient routing protocols are important as they prolong nodes battery lifetime. Routing protocols that use the ETX metric can find energy efficient paths, which allow the overall reduction of the networks energy consumption.

Table 1 provides a summary of related multi-objective optimization work based on MOEA algorithms used, scenarios considered and the metrics used as objective functions.

**Table 1**
Summary of related work.

| Publication | MOEA algorithm | Scenarios considered | Metrics considered |
|---|---|---|---|
| [15] | MODE | Wireless sensor network | Energy consumption, delay |
| [16] | MODE, NSGA-II | Full-connected network | Energy consumption, delay |
| [17] | NSGA-II | Wireless Mesh Network | Bandwidth, packet loss, energy consumption and delay |
| [18] | RVGA | Wireless Mesh Sensor Network | Energy consumption, battery lifetime |

## 3. Problem formulation

The notation and terminology used is borrowed from [19]. A Wireless Multimedia Sensor Network can be represented by a connected graph $G(V, E)$ where $V$ is the set of vertices representing nodes and $E$ is the set of edges representing links between the nodes. Each edge $e = u \to v$ is associated with $k$ weights where $\omega_l(e) > 0$, $\forall e \in E$ and $1 \le l \le k$. Similarly to [19], it is assumed that all constraints are path constrains, and that the weight of a path is equal to the sum of the weights of all edges on the path. Thus, for each path $p = v_0 \to v_1 \to \cdots \to v_n$, $\omega_l(p) = \sum_{i=1}^{n} \omega_l(v_{i-1} \to v_i)$. A path constraint, e.g., delay, represents the end-to-end QoS requirement for the complete path.

**Definition 3.1** *(Multi-constrained QoS routing problem).* Given an undirected graph $G(V, E)$ with each edge $e$ is associated with $k$ weight functions where $\omega_l(e) > 0$, $\forall e \in E$ and $1 \le l \le k$. A constants vector $c = (c_1, c_2, \ldots, c_k)$. A multi-constrained QoS routing problem consists in finding a path $p$ between a source $s$ and destination $d$, so that, $\omega_l(p) \le c_l$, where $1 \le l \le k$.

**Definition 3.2** *(Multi-constrained Optimal QoS routing problem).* Given an undirected graph $G(V, E)$ with each edge $e$ is associated with $k$ weight functions where $\omega_l(e) > 0$, $\forall e \in E$ and $1 \le l \le k$ and a path $p = v_0 \to v_1 \to \cdots \to v_n$ is considered an optimal QoS path from $s$ to $d$, if $\exists q = s \to \cdots \to d$ such that $\omega(q) < \omega(p)$.