Energy-efficient Routing

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***Abstract*—This work is focused on explore different heuristics that may be applied to provide a link-based cost for energy-aware multihop routing for wireless environments which integrate heterogeneous devices that are carried or owned by Internet end-users. We propose to analyze based on simulations of the different heuristics when applied to both distance-vector and link-state approaches, namely the AODV and OLSR routing protocols.**

***Keywords*-Multihop routing; energy-efficiency; user-centric networks; AODV; OLSR.**

I. Introduction

User-centric wireless environments integrate a highly dynamic behavior of mobile nodes, in particular of nodes that are owned or carried by humans. Examples of such environments and dynamism are the need to autonomously start a network based on end-user devices after a disaster of some nature (e.g., disaster networks) or even the need to assist emerging markets in remote areas, sometimes highly populated. Such user-centric environments attain specific requirements, of which *energy efficiency* is one of them.

Albeit being spontaneously deployed, user-centric environments rely on traditional multihop routing approaches. Multihop routing has been extensively analyzed and optimized in terms of resource management, but in terms of energy efficiency there is a lack of a thorough analysis in particular in what concerns user-centric environments such as *User-provided Networks (UPNs)* or *Mobile Ad-hoc Networks (MANETS)*. On the other hand, there is considerable related work in the fields of energy efficiency and energy awareness for sensor networks. Even though it is relevant to consider the results achieved in such networks, there are specific requirements of user-centric environments which makes energy awareness and efficiency problems not trivial to be solved. Firstly, nodes in user-centric networks are expected to be heterogeneous in terms of resources such as battery capacity. Secondly, such nodes exhibit frequent movement and are also expected to frequently join and leave a network. We refer heterogeneous for the different nodes regarding mobile devices, such as the technology itself (e.g., laptop, smart phone), battery capacity, energy consumption and energy parameters. Regarding movement, we consider a social mobility model which the parameters, such as frequency of movements, are characterized by the mobility pattern.

The main goal of our thesis proposal is focused on making current multihop routing approaches (shortest-path based) adequate for user-centric environments. In such environments there are several requirements to be met in terms of energy awareness, by exploring new routing metrics that take into consideration the state of a node (node-based perspective) or not only the originating node's perspective, but also the potential of successors (link-based perspective) in terms of energy awareness. Our expectations are to optimize network utilization by optimizing the energy-awareness of multihop routing approaches. We emphasize that the line of thought in our work is to consider at an instant in time a metric that is capable of capturing not only the perspective of a source node, but also being able to capture such notion within the context of the associations that any node may have to its neighbors, in particular to its successors. In other words, it is our belief that such metric should be able to capture energy-awareness from the perspective of the routing association between two nodes. This is different than the perspective of the link energy-awareness capability, which is common literature related to as the link quality perceived by a node.

This work is organized as follows. Section II describes selected related work focused on multihop energy efficiency. Section III presents the energy awareness in multihop routing. Section IV is our proposed heuristics emphasizing our contributions. In section V we describe the tools and implementations to apply the proposed heuristics under routing mechanisms, namely OLSR [1] and AODV [2] protocols. Conclusions and future work are presented in section VI.

II. Related Work

There are few approaches [3], [4] that have surveyed multihop proposals focused on energy efficiency, considering both the energy spent when nodes are engaged in active communication or inactive communication (e.g., in idle mode). Such work has as underlying scenarios homogeneous environments, and always assume the single perspective of the sender node. Specifically attempting to make multihop routing more flexible, some proposals [5], [6] have explored new metrics having in mind different types of optimization, e.g., reduction of energy spent across a path or avoiding nodes with low residual energy, on the global network.

Attempting to understand optimal properties that multihop routing should globally consider, C. K. Toh provides a relevant overview [7] of different routing properties to consider. In this work, the author also addresses the performance of power efficiency in ad-hoc mobile networks by analyzing four approaches which have as common goal to select an optimal path, being the optimum the minimization of the total power required on the network (across all nodes) and also the maximization of the lifetime of all nodes in the network. However, our work proposes addressing energy awareness not only from a sender's perspective but from an association between two nodes, i.e., link perspective.

III. Energy Awareness

A *node* i represents a wireless heterogeneous device with a single or with multiple network interfaces. Edges interconnecting nodes are represented as *links* (i, j) with a cost which is a measure of energy expenditure. Such energy expenditure can be obtained from a single node, a link, or network utilization perspective. From a single node perspective, there are three main modes of operation which depend on the node status. A node is in *Transmit mode* when transmitting information. Hence, *Transmit Power (Tx Power)* for a node corresponds to the amount of energy (in Joules) spent when the node transmits a unit (bit) of information. A node is in *Receive mode* if it is receiving data. Hence, *Reception Power (Rx Power)* for a node corresponds to the amount of energy (in Joules) spent when the node receives a unit (bit) of information. Particularly for the case of 802.11, there are two additional states a node may be at. When not receiving or transmitting, the node is still listening the shared medium (*overhearing*) and is said to be in *Idle mode*. When the node is not overhearing, then it is said to be in *Sleep mode*.

Another relevant parameter to consider from an energy-awareness perspective is a node's degree, N_i as the surrounding nodes impact the transmission channel heavily, as well as on energy consumption. We use the node degree definition where N_i corresponds to the amount of neighbors that a node i has at an instant in time. More relevant than the number of neighbors, is the history of variation of N_i through time.

The main energy-aware metrics for user-centric environments are the residual energy and drain rate. The *Residual Energy (RE)* of a node i, RE_i [8] is defined as the amount of energy units that the battery of node i has at an instant in time. The *Drain Rate (DR)* of a node i, DR_i [9] is defined as the amount of energy being spent by node i through time, due to the activities the node is performing. $DR(i)$, can be computed by applying an *Exponential Weighted Moving Average (EWMA).* The DR alone simply provides a way to measure energy being spent by nodes.

For heterogeneous environments, a combination of the DR with the RE of a node is significant to capture both the expenditure and the resources still available. Kim et. al. consider the ratio between RE and DR as C_i defined as node lifetime. However, all of these metrics still relate to a node perspective only, which may affect path robustness.

IV. Proposed Heuristics

This section provides an overview on the heuristics that we are currently testing, to provide multihop routing with better energy-awareness. Our proposal is to consider routing metrics that can be coupled to any multihop routing protocol.

A. Heuristic 1: Energy-awareness Ranking of Node Based on Idle Times

In this first heuristic we take into consideration the periods over time where i is in idle mode. In other words, over time we estimate how much time of its lifetime has node i been in idle mode, to then provide an estimate on a potential behavior in the future, as this will for sure impact the node's lifetime. Such periods are the ones the most expensive to i in terms of energy, and in those periods, the node degree becomes highly relevant as the more nodes surround node i, the worst the energy expenditure of i. So we consider the total period in idle time, t_{idle} over the past period together with the estimated lifetime of the node, as provided in equation 1.

$$E_{1_i} = \frac{t_{idle}}{T + C_i},\ E_{1_i} \in [0, 1] \quad (1)$$

E_1 is therefore a node weight which provides a ranking in terms of the node robustness, from an energy perspective, and having as goal to optimize the lifetime.

B. Heuristic 2: Energy-awareness Ranking of Node Based on Idle Times and Node Degree History

This second heuristic considers also the potential impact that the node degree may have in the energy expenditure of a node. Surrounding nodes impact the conditions of the wireless media and as such, the node degree history, in particular the variability of the node degree is one additional aspect that may impact node lifetime. Hence, still following a simplistic approach, we consider ways to combine the history of the node degree with E1, having derived as a first approach E2, provided in equation 2.

$$E_{2_i} = \frac{t_{idle}}{T + C_i} * N'_i, \quad (2)$$

For instance, let us assume that node i has, at a specific instant in time, a lifetime that seems to be long. If the node has an history of a low number of neighbors as happens in the case of less dense networks, then in contrast to a node that has the same lifetime but a larger number of nodes around, we can decide on which node to opt. Deciding for a node that has a higher node degree implies having more alternate paths being the flip-side to this the possibility of seeing an abrupt change in the time left until the node exhausts energy. Opting for a node with a lower node degree may provide more robustness at the cost of having less alternate paths. Depending on the situation of the nodes around (e.g. movement; short lifetimes), there is a variability associated. The node degree history, N'_i, is provided by an *Exponential Moving Average (EMA)* as provided in equation 3.

$$N'_i = \alpha \times N_{i_{t-1}} + (1 - \alpha) \times N'_i \quad (3)$$

C. Summary and Contributions

The ranking of a node considering the different heuristics can be seen from an energy-wise point of view on the global network and the impact of the heuristic considering the slope variations of the cost functions as shown in Table I. The heuristics can be applied as node-based perspective and link-based perspective. As a link cost, we consider not only a perspective of a node but also the perspective of potential successors at the same instant in time. Our contributions will provide a complete analysis based on simulations of the heuristics and different energy metrics when applied to both distance-vector and link state approaches.

Table I
RANKING THE NODE/LINK COST

t_{idle}	C_i	Ranking E_{1_i}	N'_i	Ranking E_{2_i}
high	high	candidate	high	low potential
			low	candidate
high	low	low potential	high	low potential
			low	good potential
low	high	good potential	high	good potential
			low	candidate
low	low	avoid	high	avoid
			low	low avoid

V. PERFORMANCE EVALUATION

We have considered the NS-2 simulator (version 2.34) with a realistic physical layer including a radio propagation model, radio network interfaces and the IEEE 802.11 MAC protocol. We have used the 802.11g parameters, namely, a data rate of 54 Mbps and a radio range of 250 meters. The nodes have been simulated to hold different energy characteristics, in order to represent heterogeneous portable devices, e.g. laptop, PDA, a device with continuous power. We have used the Akaroa2 [10] tool which can have as input the NS-2 output, and can assist us in adequately devising results to extract statistically independent results.

The heuristics are being analyzed from a perspective where the purpose is to increase network lifetime. As such, the results that are being extracted, are: (i) End-to-end (e2e) delay, (ii) Throughput, (iii) Aggregate node lifetime.

A. Routing Mechanisms: AODV and OLSR

Our heuristics are being developed to be applicable to any shortest-path based protocol. In our work we expect to evaluate the heuristics with OLSR and with AODV.

We have considered the native AODV, as distance vector approach, in NS-2 simulator referenced in this work as *AODV-native.* Native AODV considers hop count as the metric to compute a shortest-path. Moreover, the original C_i has been developed to be applied to DSR protocol, which selects a best path based on a max-min approach, where the best path is the one that has the lowest bottleneck in terms of energy. Then, we adapt the AODV to select the path in a min-max way as the original specification of the C_i and to test our heuristics. The modifications is only regarding using the energy metric instead of hop count by change the control messages of the AODV.

As a link state approach, we are considering the native OLSR implementation in NS-2 simulator. Native OLSR considers hop count as the metric to compute shortest-path. For the energy-aware implementation, we also modified the OLSR to allow running the original C_i cost function and also to test our heuristics. The modifications on the control messages is needed to reflect only regarding the metric.

VI. CONCLUSIONS AND FUTURE WORK

Energy efficiency is a key aspect to consider in user-centric routing environments. We proposed an energy-awareness ranking of node based on idle times, which a node provides a ranking in terms of the node robustness to optimize the node lifetime as well as the global network lifetime. Then we consider the impact of node degree history for ranking the node to extend the lifetime. The expectation that we consider through simulation is to opt for a node more robust in terms of energy allowing to preserve the energy resources selecting a path robust too.

As a future work, we are working on providing an analysis based on simulations of the different metrics and heuristics when applied to both distance-vector and link state approaches namely, the AODV and OLSR routing protocols.

ACKNOWLEDGMENT

This work is supported by Fundação para Ciência e Tecnologia, Portugal, under the PhD (FCT BD) scholarship number SFRH/BD/44005/2008.

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