A Composite Routing Metric for Wireless Sensor Networks in AAL-IoT

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***Abstract*—Ambient Assisted Living (AAL) is a concept that seeks to provide most autonomy, security, and health services for elderly people offering technology solutions to them. When AAL applications are provided through the Internet, it is possible to create new applications involving the concept of Internet of Things (IoT). The AAL-IoT applications can be used to event detection (such as fall detection or blood pressure) and send messages to an emergency service or a family member through the Internet. The event detection is frequently performed by sensor networks. However, these networks can present some difficulties to provide the high quality of service required for AAL-IoT applications. Thus, this paper proposes a new routing metric that considers information about the nodes and their connections, seeking the network performance enhancement for AAL-IoT. The proposed metric is an additive composition of information about link quality and nodes energy. The results obtained through simulation show that the proposed routing metric can increase the network performance to better meet the AAL-IoT requirements.**

***Index Terms*—Ambient Assisted Living; Internet of Things; Routing Metrics; Wireless Sensor Networks**

I. Introduction

Ambient Assisted Living (AAL) is defined as the use of different technologies to provide a better quality of life to people, regardless their ages. Elderly people commonly need more attention and AAL approaches are suitable for persons older than 64. Event detection is a topic frequently present in AAL applications [1]. The low cost and the advantages of sensor technologies turn them commonly used in AAL solutions with the goal of event detection and monitoring. When these sensors communicate and exchange data among them, a wireless sensor network (WSN) is performed.

A WSN can be defined as a set of nodes with ability to gather (environmental) data and forward the collected data to a sink node through wireless communications. In most cases, the nodes of a WSN have hard limitations of processing, storage, memory, and energy (provided by a battery). In AAL applications, a WSN can collect data from a human body either directly or indirectly (referred to as body sensor network) to infer something about the person or observed environment.

The use of Internet to forward the events detected in an AAL application to a person or to others sensors interested in the collected data may characterize an application of Internet of Things (IoT). IoT is a novel paradigm that seeks to allow data exchange among things (or objects, in general) providing a machine-to-machine (M2M) communication. To this end, IoT can use different kinds of technologies, such as radio frequency identification (RFID), WSNs, near field communication (NFC), long-term evolution (4G LTE), and WiFi [2]. According to [3], the use of M2M technologies in mHealth applications can benefit both patients and healthcare providers. Thus, combining the concepts of AAL and IoT, it is possible to develop innovative solutions so called to as AAL-IoT.

An AAL-IoT application may use sensor networks to event detection tasks. This kind of applications can require a high performance of the network, such as low latency and high delivery packet ratio. However, sensor networks may present some limitations to provide these requirements. Thus, it is important taking into account the application requirements to deploy a network able to attend it. An efficient routing protocol may be an alternative to reduce the limitation of a sensor network in AAL-IoT environments. However, the most used routing protocols do not consider the specification of AAL-IoT applications and, with this, it may not provide a satisfactory performance. For these routing protocols, the main issue comes from the fact that they only use a routing metric based on distance to perform the communication between a given node and a sink. It does not consider the quality of links and the nodes energy that composes a route may reduce the network efficiency. Then, this paper proposes a new routing metric that considers different network information seeking to reduce the network limitation for AAL-IoT applications. The proposed routing metric takes into account the quality of link and the energy level of nodes to obtain a value that should be used by routing protocols to select the best path to forward a message.

This paper is organized as follows. Section II addresses the topic of AAL-IoT and the network challenges for this kind of applications while Section III discusses some important routing metrics and its limitations in AAL-IoT scenarios. Section IV presents the proposed composed metric for routing protocols used for AAL-IoT applications and the results obtained with the use of proposed composed metric are discussed

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in Section V. Section VI concludes the paper and proposes further research works.

II. Network Challenges for AAL-IoT Applications

Considering the AAL-IoT applications, the data exchange latency among a sensor node and the sink need being as low as possible. Once an emergency situation is detected, the collected data must be quickly sent to a hospital or a relative of the assisted person. In some cases, like sudden falls and heart attack, some minutes or even seconds may avoid greater problems. [4]. This peculiar feature of some AAL-IoT applications requires that network may be able to provide a real or soft-real time data exchange.

Taking into account the importance of data exchanged among the nodes in an AAL-IoT solution, the reliability of packet delivery is also an important issue to address [5]. A sensor network needs to provide a high packet delivery rate to answer the application expectations. The routing protocol is the network component responsible for offering an end-to-end communication among the nodes [6]. Thus, it is important that a routing protocol can be able to provide a high delivery ratio, seeking to increase the efficiency of an AAL-IoT application.

Energy saving is the most studied challenge in sensor networks [7]. The use of energy-aware mechanisms can improve the network lifetime as well as the application execution period. To maintain a good performance, it is important that the network nodes may be fully operant by the maximum possible time. With this, it is essential the use of an efficient routing protocol. Furthermore, a robust routing protocol must be able to avoid routes with a low level of energy [8]. The use of routes that contain nodes with depressed batteries can cause a broken router and, consequently, the packet loss. Looking for the importance of the data sent in an AAL-IoT application, the packet loss can result in a low efficiency of the application causing irreparable people damage.

As above-mentioned, although the use of sensor networks allowing the existence of AAL-IoT most ubiquitous and pervasive, the network stills some limitations. An alternative to reduce these issues is the use of most efficient routing protocols created according to their application requirements. In a sensor network, routing protocols should be robust and fast-enough to supply the applications requirements and, at the same time, being simple and light to be executed in nodes with great hardware limitation. Thus, the development of routing protocols able to meet all these requirements is not an easy task.

One of most used routing protocols in sensor networks is the *Ad Hoc On-demand Routing Protocol* (AODV) [9]. AODV is a reactive and flat-based routing protocol initially developed for mobile ad hoc networks. Given its reactive characteristic, AODV creates routes only when a node needs to send a message. To create new routes, a node should generate a Route Request (RREQ) message with the address of the desired destination. RREQ is sent in broadcast to the neighbor nodes. Each node that receives a RREQ should verify if it is the destination of the message or if it has a route to the destination. If positive, the node should create a Route Reply (RREP) message to answer the RREQ message. RREP messages are forwarded until the RREQ originator is achieved. On the other hand, if a node that receives RREQ message is neither the destination nor has a route to the destination, the RREQ message is re-broadcasted to other nodes. This process occurs until the path construction between the RREQ originator and the required destination.

RREP and RREQ messages used in the process of the route set up have a field named *hop count*. The *hop count* is incremented when a control message is forwarded. Nodes store the hop count to each destination in its routing table. This information is used to select the shortest path to a destination at the moment of data routing. Aiming to maintain routes always updated, the nodes may exchange short control messages, called HELLO. Frequently, HELLO messages are sent by the node to inform its neighbors that it is present in the network. When an expected HELLO message is not received, the node may generate Route Error (RERR) messages to inform its neighbors that a node was lost and a route may have been broken.

As an alternative to AODV, [10] proposes a new routing protocol for Internet of Things networks, called *Routing Protocol Based on Energy and Link Quality* (REL). REL is an AODV enhancement that proposes the use of energy and link quality information in path selection process. Besides *hop count* field, RREQ and RREP messages have two other fields: *weak links* and *energy*. *Weak links* field is used to informing the number of nodes with low link quality in a path. Thus, *weak links* field is incremented always that a message is received with an LQI (Link Quality Indicator) less than a threshold. *Energy* field is used to inform the residual energy of nodes. Each time t, node verify its residual energy E and stores it (E_t). If $E_t - E_{t-1}$ is highest than a predefined threshold (E_{th}), a Route Advisor (RADV) message is sent by the node advising the updated energy information to its neighbors. The path selection in REL uses an algorithm that compares two routes: an active route and a candidate route. The algorithm first compare the route *energy* levels, in sequence, the *hop count* and, by the end, the number of *weak links*.

The AODV protocol may be sufficient to satisfy the requirement of a simple application. However, in its default configuration, AODV may not be able to supply the requirements of AAL-IoT applications. The use of *hop count* as a routing metric to select the best path to forward a message is neither able to capture the quality of links nor the energy level of nodes that composes a route. Without considering this important information, the routing process may have a reduced performance generating a high packet loss rate. Consequently, energy consumption may be increased with the necessity of resending lost packets. Seeking provide a better quality of service for IoT networks, REL protocol considers information about energy and link quality. However, the protocol is strongly based on thresholds. A bad definition of this threshold may reduce the network performance. Also, the use of RADV messages may increase the energy spent with control messages and, consequently, reducing the network lifetime. By the end, the REL path selection algorithm seeks, initially, paths with highest energy level. This approach can select routes with low reliability and high hop count. Thus, the use of REL may not be a good alternative for AAL-IoT applications once this may not supply the network requirement of this kind of application.

In the following section some routing metrics that can be used together with the routing protocols to create an alternative solution for AAL-IoT application requirements are described.

III. Routing Metrics for IoT Networks

The network performance is directly related to the routing protocol as well as its metric to define the weight of each link in a path. Only after computing the path cost, the routing protocol will be able to define the best path to forward a packet [11]. A routing metric defines a quantitative value that is used to evaluate the paths among two nodes. These metrics are commonly categorised into two types: node metrics and link metrics [12]. The node metrics consider aspects of the node, as energy capacity, expected lifetime, antenna sensitivity, etc. On the other hand, the link metrics expose information referred to the connection between two nodes as throughput, delay, error bit rate, link quality and other channel characteristics [13].

In [14], J.L. Sobrinho presents a routing algebra where a network is defined as a strongly connected directed graph composed by a set of nodes and a set of edges that represents a connection among nodes. The authors in [15] mention that a routing metric can be represented by the quadruplet $(S, \oplus, \omega, \preceq)$ called of *path weight structure*, where:

- S: is the set of all paths;
- $\oplus$: is the path concatenation operation;
- ω: is a function that maps a path to a weight;
- $\preceq$: is an order relation.

Considering $a, b \in S$, the expression $a \oplus b$ represents the concatenation of paths a and b. $\omega(a)$ and $\omega(b)$ define the weight of paths a and b considering the used metric such as hop count, link quality, delay, etc. The relation $\preceq$ provides the weights ordering where $\omega(a) \preceq \omega(b)$ means "a is lighter (better) than or equal to b".

The routing algebra objectives to provide methods for the routing protocol evaluating the paths between two nodes and select the lightest. To that end, the routing algebra introduces the primitive properties of monotonicity and isotonicity. A routing metric is monotonic if and only if $\omega(a) \preceq \omega(a \oplus b)$ and $\omega(a) \preceq \omega(c \oplus a)$ holds $\forall a, b, c \in S$. A routing metric is isotonic if $\omega(a) \preceq \omega(b)$ implies both $\omega(a \oplus b) \preceq \omega(b \oplus c)$ and $\omega(c \oplus a) \preceq \omega(c \oplus a)$, $\forall a, b, c \in S$. (See [15] to complete definition).

In short, according to [11], a routing metric is monotonic if the weight of a path can be only increased, never decreased. If a metric includes this feature, it can be considered loop free. On the other hand, a routing metric is isotonic if the order of two paths weights is preserved whether they are linked to a common third path. If a metric holds this feature, the paths created by the protocol are considered optimal.

The following subsections present some routing metrics, called primaries, just to consider only one network aspect.

A. Hop Count

Hop count (HC) is one of the most frequent metrics and it is used in several protocols as AODV and REL. HC reports the number of nodes that composes a path. The weight ω of a path a ($\omega(a)$) is the sum of the links that creates the path. The operation of concatenation $\omega(a \oplus b)$ is equals to $\omega(a) + \omega(b)$, $\forall a, b \in S$. The order relation $\preceq$ is the "less than or equal", where the lowest values are better. Being isotonic and strictly monotonic, efficient algorithms that use HC can find loop free path with the minimum number of links [16]. However, as they do not regard distinct transmission rates, packet loss ratios, communications interference or other metrics, the HC may not result in good performances.

B. Remaining Energy

Remaining Energy (RE) is a metric used by energy-aware routing protocol with the objective to increase the network lifetime. RE value determines the lowest energy level between the nodes that compose a path. Thus, the weight of a path a is obtained using $\omega(a) = min\{RE^i | i \in P\}$, where P is the set of nodes that composes the path a, i is a path node, and RE^i is the ratio between the initial energy and the current energy value. The concatenation operation is $\omega(a \oplus b) = max\{\omega(a), \omega(b)\}$. If a node needs to select between a path either a or b, the order relation $\preceq$ is namely the "less than or equal". Thus, considering $a, b, c \in S$ and $\omega(a) < \omega(b)$, it may happen that $\omega(a) < \omega(b) \leq \omega(c)$ in which case $\omega(a \oplus c) = max\{\omega(a), \omega(c)\} = \omega(c) = max\{\omega(b), \omega(c)\} = \omega(b \oplus c)$. With this, RE metric is neither strictly isotonic nor monotonic.

With the use of RE metric, the routes that have nodes with lower battery levels will be avoided. Thus, the packet loss caused by energy exhausting tends to reduce. However, as above-mentioned, the RE is not strictly monotonic and can generate loops in the forwarding packet process. Paths with loops increase the network energy consumption and the probability of packet loss, besides reducing the network lifetime.

C. Link Quality Indicator

Link Quality Indicator (LQI) is a parameter offered by the standard IEEE 802.15.4 physical layer which aims to represent the quality of a link at the moment of a frame reception [17]. LQI values change between 0 and 255 where the greater value represents the better link quality between two nodes. Thus, LQI is a dynamic metric that defines the quality of a link locally. To allow the use of LQI to quantify the quality of path from the beginning to the end, some authors propose different techniques. In REL and [18], a threshold based on LQI value is used to avoid path with *weak links* in a lexical routing metric.

IV. Proposed Metric for Routing Protocols Used in ALL-IoT

AAL-IoT applications are commonly used for event detection in an environment with elderly people. To perform this task, sensor networks may be a non-invasive alternative to collect and analyze data for inferring something about the physical or cognitive status of an observed person. However, the most used routing protocols in sensor networks may have some drawbacks that reduce the performance of the applications. With this, it is important the use of alternative methods to increase the routing efficiency aiming to provide a better service to a AAL-IoT application. Thus, this paper proposes a composite routing metric as an alternative to hop count at AODV with the objective of enhancing the routing process.

The proposed routing metric considers two primary metrics: LQI and RE. LQI metric is used to provide information about the link condition in the path seeking select routes with the highest reliability and low delay. RE metric is used to consider the energy information of a path and to avoid the use of routes with low energy level. Thus, with the composition of these primary metrics, it is expected to reduce the impact of sensor network limitations at AAL-IoT applications. Therefore, it is important the composite metric meets the monotonicity property to hold the loop free feature for the routing protocol [16].

In [19] is defined the additive routing metric composition. Considering two paths a and b, the additive composition order relation $\prec_{add}$ for the routing metrics ω_1 and ω_2 is presented in Equation 1.

$$(\omega_1(a), \omega_2(a)) \prec_{add} (\omega_1(b), \omega_2(b)) \Leftrightarrow \omega_1(a) + \omega_2(a) < \omega_1(b) + \omega_2(b)) \tag{1}$$

The strict monotonicity of the additive routing metric is held by the combination of two strict monotonic primary metrics. Also, the primary metrics used in the composition should have the same order relation to producing coherent results. Thus, to enable the use of LQI and RE in an additive composite routing metric, it is necessary to adjust the relation between these two metrics.

As shown in Section III, the RE metric is not monotonic. With this, to convert the RE metric for that, it is proposed a new way to calculate the metric. The Equation 2 shows the RE metric used in the present proposal. Then, E_n represents the current remaining energy percentage in the node's battery and t is a float value that can change between 0.0 and 1.0. t value is used to accentuate the RE value of nodes with an energy level very low. The t value should be adjusted according to the necessity of avoiding paths with low energy level. As greater is t, greater will be the value of RE.

$$RE = 2^{(\frac{1}{E_n})*t} \tag{2}$$

LQI metric is commonly used with a threshold to separate good links and weak links, such as presented in [10]. However, although they may meet the monotonicity property, the use of a threshold to define the quality of a path may not reveal the real path condition. Therefore, this paper uses a distinct way to consider every LQI value of a path. The called ***LQI End-to-end*** (LQI_{e2e}) considers the quality of a path taking into account the LQI value obtained in each hop, from the sender node to the receiver. Equation 3 presents the LQI_{e2e}, where LQI_{max} is the maximum link value (255) and LQI_r is the LQI value calculated at the lower layer (MAC layer) in a moment of packet receiving. Routing metrics LQI_{e2e} and RE are formally described in Table I, where n represents each link in a path.

$$LQI_{e2e} = \frac{LQI_{max}}{LQI_r} \tag{3}$$

TABLE I
Primary routing metrics formally defined

	LQI_{e2e}	RE
$\omega(a)$	$\sum_{i=1}^{n} LQI_{e2e}{}^{i}$	$\sum_{i=1}^{n} RE^{i}$
$\preceq$	$\omega(a) < \omega(b)$	$\omega(a) < \omega(b)$
$\oplus$	$\omega(a) + \omega(b)$	$\omega(a) + \omega(b)$

In this work, the use of the proposed routing metric is performed with the AODV routing protocol. RE and LQI_{e2e} values are loaded in specific fields of routing control message (in the case of AODV, RREQ, and RREP messages) that are exchanged among the nodes at the moment of routes setup. When a node receives a routing control message, it calculates the LQI_{e2e} value and stores it on its routing table. RE is stored as received in the message. To forward a control message, if necessary, the node must 1) sum RE of the message with its RE and insert the result in the RE message field; 2) refresh the LQI_{e2e} message field with the LQI_{e2e} value calculated at the moment of the message reception. The information stored in the routing table is attached with the addresses of the node that created and the node that sent the message.

At the moment of data packet forwarding, the node must calculate the quality of each path between it and the destination node. The information previously stored in the routing table is used to define the path quality based on the proposed composite routing metric using the function in Equation 4. Thus, α and β are values between 0.0 and 1.0 used to define the weight of metrics LQI_{e2e} and RE, respectively, at the moment of path quality computation. With these parameters, it is possible to adjust the routing metric to prioritize either routes with better link quality or routes with higher energy level. The order relation $\preceq$ is "less than or equals". Thus, the lowest $\omega_{prop}(a)$ represent the best path.

$$\omega_{prop}(a) = \alpha * \omega_{LQI_{e2e}}(a) + \beta * \omega_{RE}(a) \tag{4}$$

The following section analyses the results obtained for the proposed routing metric in comparison with other approaches.

V. Results and Discussion

This paper proposes a new routing metric based on link quality and residual energy to provide the requirements of AAL-IoT applications. Aiming to validate the proposed metric, computational simulation studies using Castalia [20] were performed. Castalia is a simulator especially developed for sensor networks. The considered network scenario includes 36 sensor nodes placed on a 6 x 6 grid in an area of 30 x 30 meters. The objective of the simulated AAL-IoT application used over the network is detecting events (i.e., an elderly patient fall) that occurs in the monitored area. Each detected event must be sent to the sink node (located in the top-right) that is responsible for contacting an emergency service or contact a patient's family through the Internet.

The proposed routing metric was developed to be attached to the AODV and compared with AODV in its standard version and REL. α and β parameters of the proposed routing metric were set to as 0.5 for both parameters. Looking to attend the requirements of AAL-IoT applications, the performance evaluation was achieved in terms of packet delivery ratio, spent energy to each bit delivered, and average latency.

Figure 1 shows the obtained results for the packet delivery ratio. Considering the simulated scenario, the use of the proposed routing metric shows better results when compared with the AODV and REL routing protocols. The proposed routing metric increases the performance of standard AODV by means of 67%. Packet loss occurs in the sequence of several aspects, such as interference, noise, and low link quality between the nodes. Due to the use of LQI in the process of measurement of route quality, the proposed routing metric is able to select paths with high reliability reducing the packet loss. Moreover, with an efficient composition of primary metrics, the proposed metric is able to avoid path with low energy level and weak link quality. Thus, the probability of a packet being forwarded through a bad route is reduced, increasing the packet delivery ratio. At the same time, the results exposed in Figure 2 shows that the spent energy to delivery the collected data with success to the sink is reduced. With the use of the proposed metric, considering the evaluated scenario, the spent energy to delivery each data bit is decremented when compared with standard AODV and REL. With a high packet delivery ratio, the proposed metric achieves the packet delivery without resending many messages. Thus, less energy is spent to forward the collected data to the sink node, resulting in the reduction of the consumed energy by the network. As a consequence of it, the network lifetime is increased, improving the AAL-IoT application efficiency and preserving its execution for a greater period.

In terms of latency, Table II presents the results obtained by the performed experiments through simulation. Considering the evaluated scenario and based on the results, the proposed approach can transmit the detected events more quickly. Results show that approximately 85% of sent messages using the proposed metric are delivered with less 40ms, while using standard AODV or REL the messages are delivered in

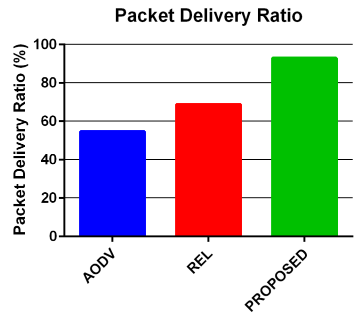

Fig. 1. Percentage of the average packet delivery ratio for AODV, REL and the proposed routing metric.

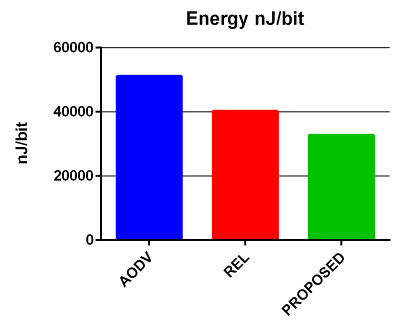

Fig. 2. Average spent energy to send each bit for AODV, REL and the proposed routing metric.

approximately 65% and 75%, respectively. Once again, a good combination of primary routing metrics enables the obtainment of an efficient network performance. Thus, the fast message transmission performed by the proposed routing metric may be able to better provide the low latency required for AAL-IoT applications, when compared with other protocols studied and considering the evaluated scenario.

TABLE II
Average Latency in Percent

Protocol /Metric	Average Latency (ms)			
	[0,20)	[20, 40)	[40, 60)	>60
AODV	6%	59%	18%	17%
REL	17%	58%	17%	8%
PROPOSED	26%	59%	5%	10%

VI. Conclusion and Future Works

Sensor networks are commonly used in AAL-IoT applications given their availability for event detection tasks. However, this kind of applications require a high-quality of networks service. Seeking better provisioning for the AAL-IoT requirements, this work proposed a new composite routing metric based on link quality and remaining nodes energy. To measure the performance of the proposed metric, it was embedded in AODV routing protocol and then compared with the default version of AODV and REL. The obtained results, compared to the studied protocols, shows the proposed routing metric was able to enhance the packet delivery ratio, reduce the spent energy to send collected data, and decrease the average latency to messages delivery. Thus, using the proposed routing metric it is possible to improve the efficiency of the network and better fulfilling the AAL-IoT application requirements.

For future work, a complete study of the proposed metric including the comparison of others protocols, algorithms, and metrics should be performed. Moreover, it is desired to perform simulation studies with other scenarios and create a real experimentation environment (a testbed).

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