Energy Constraint-Aware Routing Protocol for Data Transmission in Ad hoc Medical Care Networks

Yan Sun
Queen Mary University of London
School of EECS
London, UK
+44 0843 290 5186
yan.sun@qmul.ac.uk

Pei Xue
Queen Mary University of London
School of EECS
London, UK
+86 18810569705
p.xue@se10.qmul.ac.uk

Jinze Yang
Queen Mary University of London
School of EECS
London, UK
+86 18810544153
j.yang@se11.qmul.ac.uk

Chris Phillips
Queen Mary University of London
School of EECS
London, UK
+44 20 7882 7989
chris.i.phillips@qmul.ac.uk

Xiaodong Xu
BUPT National Engineering Laboratory for Mobile Network Security
Beijing, CHINA
+86 10 61198755
xuxiaodong@bupt.edu.cn

ABSTRACT

This paper proposes a novel routing protocol called Energy Constraint-Aware Routing Protocol (ECAR) for data transmission in Mobile Ad hoc Medical Care Networks (MAMCN). MAMCN is a sophisticated network environment where multiple types of mobile devices are involved, employing different forms of data transmission without a pre-defined infrastructure. Besides common data, images and "big data" are also significant contributors to the hop-by-hop transmissions. Given the real-time energy status of every node in MAMCN, the route selection scheme proposed in ECAR not only treats the application data differently, but also involves a distributed image compression mechanism as part of the overall design goal, that is prolonging whole network's lifetime. Simulation results show that ECAR out performs other routing protocols greatly in the challenging MAMCN environment.

Categories and Subject Descriptors

C.2.2 **[Network Protocols]**: Routing protocols
J.3 [**Life and Medical Sciences**]: Health, Medical Information Systems.

General Terms

Algorithms, Performance, Design, Reliability

Keywords

Energy, Constraint, Sensor, Big Data, Images, Mobility, Capability, Routing.

MobileHealth'14, August 11, 2014, Philadelphia, PA, USA
Copyright © 2014 ACM 978-1-4503-2983-5/14/08…$15.00.
http://dx.doi.org/10.1145/2633651.2633654

1. INTRODUCTION

For decades, the smart medical-care environment has been an interesting and encouraging research topic in both medicine and telecommunication fields. Recently, along with the evolution of sensor networks and wireless communications techniques, it has become feasible and practical to provide 360-degree medical monitoring and fast medical aid, not just traditional wired telemedicine, but even remotely, so called mobile healthcare [9]. The massive deployment of the Internet of Things is bringing broad growth in device-to-device applications. Sensors no longer only refer to the traditional tiny components which are fixed in a room around patients. Many other fruitfully functional devices, for instance, tablets or smart mobile phones have become powerful portable equipment with plenty of handy applications to capture real-time physiological data, including types of still pictures, videos, audio, etc. Furthermore, broadband network access provides a high-speed transmission capability to ensure expedient data collection for medical treatment purposes.

Introducing advanced wireless techniques into the healthcare business is becoming a hot research topic. With the globalized commercialization of 4th generation (4G) mobile broadband technologies, the authors in [3] propose a healthcare system aimed at combining 4G mobile broadband with Medical Body Area Network (MBAN) sensor technologies for the next generation of mobile and pervasive healthcare management systems. iResTrac is a healthcare oriented smart phone application designed in [10]. By scanning the barcode of hospital resources, iResTrac can allow staff to retrieve the information and update status information anytime, anywhere, within network coverage. The authors in [1] focus on how to process medical sensing data efficiently on mobile devices considering the tight limits on storage, computation power, network connectivity, and battery usage.

As sensors play an indispensable role in Mobile Ad hoc Medical Care Networks (MAMCN), apart from cellular networks or well-established short-range broadband wireless networks, Mobile Ad hoc networks or mobile wireless sensor network (MWSN) are another good option for supporting data transmission. One of the complications that MAMCN environments face is the various type of mobile equipment involved. Traditional sensors, smart mobile phones, tablets, wearable devices, and WIFI enabled laptops can all be employed but despite their different data processing and transmission capabilities. The other issue is the multiple types of data being transmitted. Multimedia data provides great advantages for healthcare though it represents a heavy load for communication networks. In this paper, we further investigate the routing issue in MAMCN. Taking the above two critical issues into consideration, an Energy Constraint-Aware Routing Protocol (ECAR) is proposed. Real-time node power and buffer status are measured before a route is selected. Meanwhile, different route selection strategies are applied to different data types accordingly. In particular, a distributed compression scheme for image data forms part of the route selection process. The design goal of ECAR is to extend the overall network lifetime by prolonging the critical nodes' active time in the network.

The rest of the paper is organized as follows: Section II introduces some related work. Section III introduces definitions related to node performance measures. Section IV then describes in detail how ECAR functionally works and how it performs route selection. The implementation and simulation results are evaluated in Section V and conclusions are presented in Section VI.

2. RELATED WORK

Energy consumption is always one of the essential factors when evaluating the performance of ad hoc networks or wireless sensor networks. The authors in [6] have conducted a series of experiments to measure the energy consumption of an IEEE 802.11wireless network interface operating within an ad hoc networking environment. The speed of energy drain-out on each node influences the overall network lifetime greatly. Many ad hoc routing algorithms have been proposed that aim to minimize energy consumption. One algorithm proposed early on is called Minimum Total Transmission Power Routing (MTPR) [2]. This routing algorithm finds the best route with the lowest total transmission power in order to minimize overall energy consumption. However, in fact, the network lifetime is determined by the node whose energy first drains out, not the total energy consumption. So in MTPR, though the total energy consumption is minimized, the network lifetime may still be short. As an improvement, Min-Max Battery Cost Routing (MMBCR) [2] is one of the algorithms that employ lifetime prediction, aimed at avoiding routes through node(s) that have the least battery charge. The algorithm selects the route with lowest route lifetime constraint which has the highest residual energy of all possible routes from the source to the destination. On the other hand, Lifetime Prediction Routing (LPR) in [7] adopts a special method to calculate energy drain rate to determine the node's lifetime. All in all, these routing algorithms are designed with the intention of maximizing the overall network lifetime by prolonging the on-route nodes' lifetime.

Although medical imaging data management and its lossless transfer is an important issue in healthcare, compared to regular data, image data usually requires more storage due to its naturally large size. It also consumes more power, as compression is typically required before transmission. However, the influence of image compression is missing in the above algorithms. Work in [4] points out that image compression prior to transmission is quite typical in wireless networks in order to save communication energy and storage space. The authors further claim that in ad hoc or WSN, by introducing a distributed image compression scheme, the burden on resource-constrained nodes can be shared by other nodes so the overall network lifetime can be extended.

Among various solutions, JPEG2000 is an image compression standard widely used in such energy constrained networks, which demonstrates a high compression ratio. Referring to [5], a wavelet transform forms a core part of JPEG2000 image compression, but is the most energy-consuming element due to the computational complexity. The principle of the wavelet transform is illustrated in Figure 1. In a general case, JPEG2000 will execute 5 levels of wavelet transformation for each image.

Figure 1 Compression based on the Wavelet Transform

If distributed compression is adopted, as introduced in [4], it has to be clarified that no matter which level of compression is undertaken, the energy consumption is the same, and the total transmission energy might be higher than a non-distributed image compression scheme where all the image compression is performed by the source node. However a distributed image compression scheme gives an opportunity to prolong the network lifetime due to load sharing and balancing of the power consumption.

The results in [4] and [6] also highlight another interesting point which is that the energy consumed in the compression procedure is much higher than the energy consumed for transmission and reception. Some recent research proposes distributed image compression schemes to prolong network lifetime, as described in [4] and [8]. However nodes with differing capabilities are not taken into account, which makes the simulation, results less relevant to MAMCN. Additionally, most of the routing algorithms apply the same routing strategy no matter what type of data are transmitted.

Given all of the above studies, the authors in this paper design an Energy Constraint-Aware Routing Protocol (ECAR) which is the first on-demand routing protocol with an embedded distributed image compression scheme for MAMCN. ECAR gives higher priority to resource-constrained nodes and distributes heavier loads onto resource non-constrained nodes during the route selection process. The route selection algorithm intends to optimize the overall network lifetime by particularly prolonging low capability nodes' lifetime. Highlight features are listed below:

1. Nodes are recognized by their capabilities
2. Real-time node power and buffer storage are taken in to consideration for route selection
3. Node mobility and stability are also contributors for route selection
4. A distributed image compression scheme also influences the route selection outcome
5. A single route policy applies to low capability nodes

The following sections provide details of how ECAR operates.

3. NODE RELATED MEASUREMENTS

3.1 Definition of Fundamental Attributes

In order to measure the capability of each node, a few contributors are defined below. Note that in the following equations n_1, n_2 denote constant parameters.

3.1.1 Definition of real-time Energy Degree -- E_i

$$E_i = \left(-e^{-E_i^r / n_1} + 1\right)^{n_2} \qquad (1)$$

E_i^r is the real-time residual energy of node i with $E_i^r \geq 0$. As $\lim\left(-e^{-E_i^r / n_1} + 1\right) = 1$ when $E_i^r \to \infty$ and $-e^{-E_i^r / n_1} + 1 = 0$ when $E_i^r = 0$, equation (1) guarantees E_i is within the range of $[0,1]$.

3.1.2 Definition of real-time Buffer Degree -- B_i

$$B_i = \left(-e^{-B_i^r / n_1} + 1\right)^{n_2} \qquad (2)$$

B_i^r is the real-time residual buffer state of node i and $B_i^r \geq 0$. Equation (2) guarantees the value of B_i is within the range of [0,1].

3.1.3 Definition of Operating Capability-- D_i

$$D_i = 0.1^{P_i} \times B_i \times E_i \qquad (3)$$

P_i is the power constraint indicator for node i. The values of P_i are defined as below:

1) $P_i = 1$ for nodes whose power consumption is paramount, such as sensors without a power supply.
2) $P_i = 0$ for nodes whose power consumption is not so critical, such as laptops with a charging facility.

3.2 Node and Data Classification

Based on the value of the Node Operating Capability D_i, compared to the predefined degree threshold D_{thr}, the nodes in MAMCN are grouped into two levels: High-capability node and Low-capability node.

Data is categorized into three types in this work: image (IM), big data (BD) and regular data (RD) as defined below:

IM: Image data employs the JPEG2000 standard, including high resolution medical imaging, such as digital radiography (DR), computerized tomography (CT), magnetic resonance imaging (MRI), Doppler ultrasound, digital color microscopy (DCM), and digital electronic microscopy (DEM).

BD: Big data whose size is above BD_{thr}. Therefore the communication energy consumption needs to be taken into consideration.

RD: Regular data whose size is below BD_{thr}.

The next section gives details how the route is selected in order to prolong the network lifetime.

4. ECAR (Energy Constraint-Aware Routing Protocol) Design

4.2.1 Route Discovery Process

Once a mobile node in the MAMCN has application data to send, this source will broadcast a Route Request (RREQ). Besides the conventional message fields within the RREQ, it also adds the following information before transmission: data type, Energy Degree, Residual Energy Degree and Residual Buffer Degree.

When an intermediate node (IN) receives a RREQ, if this RREQ has not been processed before and not reaching to maximum TTL, it will add its Mobility, Energy Degree, Energy Drain Rate, Buffer Degree and crossload (explained in Section 4.2.2) to the corresponding fields. Then IN will check if it is a low-capability node, if YES, further check if there is an existing route across it; if YES, it marks this RREQ with an indication for route selection purposes later. Finally IN re-broadcast the updated RREQ packet.

The destination node starts a timer after receiving the first RREQ to allow reception of multiple RREQs from the same source via different routes during a given period of time. Once the timer expires, it runs the route selection algorithm on all possible routes. Then the route with the highest route quality is chosen as the final decision. After that RREP is sent along the confirmed route back to the source node. If IM data is involved, the RREP message also assigns the distributed compression task when it confirms the route.

4.2.2 Route Selection Scheme and Algorithm

As mentioned earlier, the ECAR design intends to choose the appropriate route selection algorithm for different types of data based on their characteristics. For image data (IM), the distributed compression scheme forms part of the route setup decision process, as the power consumption is essential not only during transmission but also for performing compression. For the big data (BD), though there is no request for compression, the transmission power should be considered due to the size of the data. For regular data (RD), the stability of the route is more important compared to the other two types. Though different factors are taken into account when selecting the route, the common target of ECAR, regardless of data type, is to prolong the overall network lifetime.

4.2.2.1 Algorithm for Image Data (IM)

The strategy of the IM routing algorithm is to select a route that balances between energy demands and the node mobility, where the nodes that are close to the source node have more power storage so that they can afford to perform the image compression computation. The destination node calculates Q_{IM} for each possible route (with n nodes) as follows:

$$Q_{IM} = \min_{1 \leq i \leq n} \left[\frac{E_i}{ln\left(1 + {crossload_i}/{2}\right) + 1} \right]^{N(i)} \times \prod_{i=1}^{n} \left(\alpha_i \times \beta_i \times M_i \right) \quad (4)$$

Where

$$N(i) = 5e^{-i} + 1$$

i indicates how many hops the current node is away from the source node, and n means the total hops of the route. $crossload_i$ indicates the amount of route table entries at node i. The real-time energy degree E_i is divided by $ln\left(1 + {crossload_i}/{2}\right) + 1$ in order to avoid one node with heavy payload which might lead to excessive energy consumption and packet collisions.

The introduction of $N(i)$ means the closer to the source, the more important are the remaining energy and load factors in terms of the route selection. This design considers that the image compression should be carried out as early as possible so the initial nodes will consume more power than later ones along the path. The same number of compression levels (5-level) as in the classic JPEG2000 format is adopted in this work therefore there is no further compression required after the 5th hop. The $N(i)$ equation guarantees the value reaches 1 when i>5 and the characteristic shape of its curve reflects the energy consumption at each compression level.

M_i is a mobility indicator as equation (7) defined in [11]. α_i is a coefficient related to the energy drain rate, which refers to the rate of energy consumption and is defined as below：

$$\alpha_i = \begin{cases} 1 & \frac{R_i}{E_i} < R_{thr} \\ 0.1 & \frac{R_i}{E_i} \geq R_{thr} \end{cases} \quad (5)$$

Where E_i is the real-time energy degree indicating the remaining energy, R_i the energy drain rate defined in [7] as follows:

$$R_i = \frac{1}{N-1} \sum_{k=i-N+1}^{l} R_k(t) \quad (6)$$

The lifetime calculation described in [7] takes the real-time remaining energy and the current energy drain rate into account. There is one risk factor that might lead to a short overall network lifetime if equation in [7] is followed. Based on the lifetime prediction equation defined in [7], one node with little energy storage and low drain rate might be labeled as long lifetime node. However once it is selected for data transmission, the remaining energy cannot cope with the task and therefore shortens the network lifetime dramatically. Conversely, in this work, ECAR introduces a drain rate threshold to give more weight to the residual energy in order to avoid the risk as described in [7].

β_i is a coefficient related to the real-time Buffer Degree B_i . β_i is calculated as follows to avoid selecting nodes with little residual buffer space.

$$\beta_i = \begin{cases} 1 & B_i \geq B_{thr} \\ 0.1 & B_i < B_{thr} \end{cases} \quad (7)$$

The destination node runs the route selection algorithm for image data together with an adaptive distributed compression algorithm as shown in Figure 2. This scheme determines which node(s) along the selected route to execute the compression task. The *Distribute_forward* function assigns the next level's compression task to the next hop. The *cal_lifetime_credit* function calculates the lifetime credit for the current node based on the energy consumption at each compression level and the transmission procedure. The aim of the algorithm is to prolong whole route lifetime in the network.

Algorithm of Compression Level Assignment
rs′=[0 0 0 0 0]
while(LT_{credit}<TH && LT_{credit} > LT_{last}){
rs=rs′
rs′=*distribute_forward* (rs);
LT_{credit}=*cal_lifetime_credit* (rs);
}
rs_final=rs

Figure 2 Adaptive Distributed Compression Assignment Algorithm for IM

4.2.2.2 Algorithm for Big Data (BD)

The route selection strategy for BD is to choose more of the high-capacity nodes along the route for data transmission. The destination node calculates Q_{BD} for each possible route (with n nodes) as follows:

$$Q_{BD} = \min_{1\leq i\leq n} \frac{E_i}{\ln\left(1+\frac{crossload_i}{2}\right)+1} \times \prod_{i=1}^{n}\left(\alpha_i\times\beta_i\times M_i\right) \quad (8)$$

$E_i, M_i, \alpha_i, \beta_i, crossload_i,$ and n are defined similarly as in the Routing Algorithm for Image Data. This equation is without the power of $N(i)$ term, used for big data, as distributed compression will not be executed. This means all nodes along the route are treated equally.

4.2.2.3 Algorithm for Regular Data (RD)

The route selection strategy for RD is to choose a more stable route for data transmission. The destination node calculates Q_{RD} ffor each possible route (with n nodes) as follows:

$$Q_{RD} = \min_{1\leq i\leq n} \frac{E_i}{\ln\left(1+\frac{crossload_i}{2}\right)+1} \times \prod_{i=1}^{n}\left(\alpha_i\times\beta_i\times M_i^{M_{co}}\right) \quad (9)$$

The larger M_{co} is, more impact mobility has. As regular data is normally of relative small size, the transmission power consumption factor is less important than the mobility factor.
Once the destination node finds a suitable route, it will unicast the Route Reply (RREP) message along the selected route.

4.2.3 Low-capacity Node Single-Route Policy

For low capacity nodes, the route selection algorithm guarantees that there is only one route passing through it at the same time. So when a low capacity node receives a RREQ message, it first checks whether there is already a route saved in its routing table; if YES, it marks this RREQ and forwards it. Thus the destination knows that this node is unavailable. The low-capability node forwarding RREQ message is used to guarantee that under the single route situation, the destination node can send a Route Request Reject (RERR) message via this route to inform the source node that the request is rejected. The source node then needs to wait for a certain period of time until the existing route being used is released.

5. SIMULATION AND EVALUATION

5.1 Simulation Environment

We adopt OPNET as the simulation platform. 802.11a is chosen as the wireless access technology for MAMCN. Simulation parameters are listed in Table 1; Digital Radiography is adopted as IM with size 6M. The simulation area is 400m*400m for all scenarios. Each scenario is repeated 5 times with different random seeds. For clarity, only the mean values are shown in this section.

Table 1 Simulation Configuration

n_1(low/mid /high)	10/1K/10 K	**Original IM/BD/RD Packet Size**	6M/4.5M /2K
n_2(low/mid /high)	5/20/30	M_{co}	10

5.2 ECAR Route Selection for Different Data Types

The first scenario is to demonstrate ECAR's route selection scheme based on different data types. 20 nodes are deployed in the area. All three types of application (IM/BD/RD) are running at the source node simultaneously. One low-cap node and one moving node are configured to add a complication and variability into the scenario. For comparison, MMBCR [2] and CRMBR [11] are simulated as well. Route selection results are shown in Figure 3. Network lifetime is defined as the network duration time when the first node along the route has experienced energy drain out.

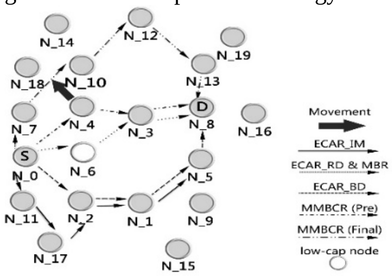

Figure 3 Route Selection for ECAR/MMBCR/CRMBR

When selecting routes, MMBCR mainly considers remaining energy; however the node's mobility and the number of hops on the route contribute greatly for the end-to-end delay. CRMBR takes node's stability into account for route selection. By avoiding unstable nodes along the route, CRMBR guarantees low delay for all data applications. However, without energy being considered, the network lifetime of CRMBR is very short. ECAR considers both lifetime and route stability during route selection, so it provides the longest network lifetime among the three protocols. Due to employing a distributed compression scheme, the end-to-end delay of IM in ECAR is much higher than MMBCR and CRMBR. Figure 4 provides further details.

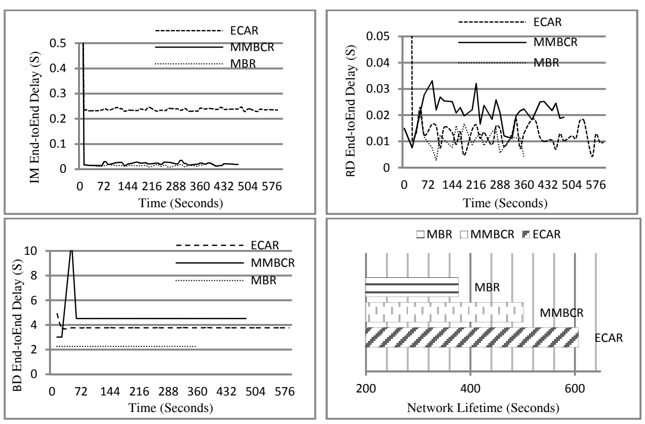

Figure 4 Scenario One: Performance Comparison for ECAR/MMBCR/CRMBR

5.3 Route Selection with Diverse Node Mobility

The last scenario investigates the influence of node mobility on ECAR's performance. 30 nodes are distributed within the area. Three to six nodes are configured with 0.5m/s speed following the direction of movement arrows. Three types of service are generated separately from three source nodes targeting different destination nodes. Transmission starts in sequence with a 5 second gap. For instance, four nodes are moving in Figure 5. LPR, MMBCR and CRMBR are also simulated under the same conditions for comparison.

Figure 5 and Figure 6 show three aspects of performance in scenario two. The IM data end-to-end delay in ECAR is much higher than for the other routing schemes due to the distributed compression scheme. However, in terms of the network lifetime and the number of link breaks during the whole transmission, ECAR performs outstandingly compared to the other protocols.

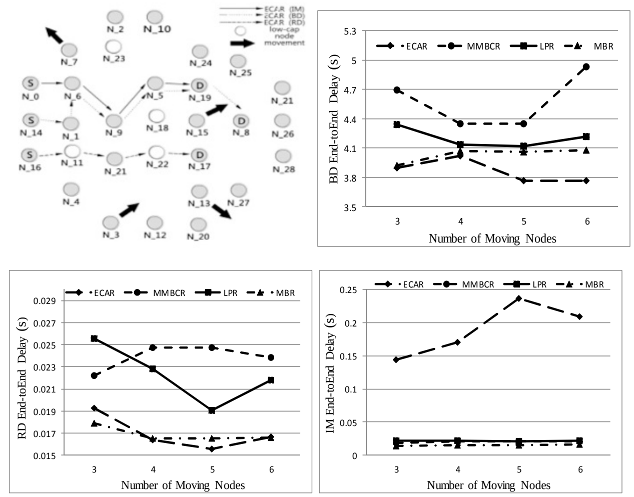

Figure 5 BD/IM/RD End-to-End Delay for various Node Movements

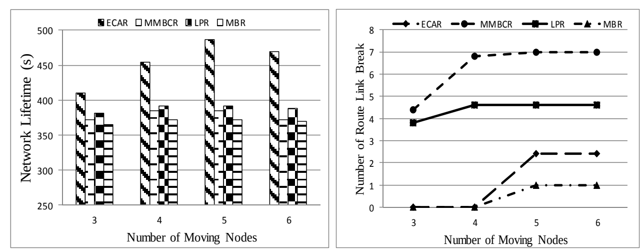

Figure 6 Network Lifetimeand Link Breaks for various Node Movements

6. CONCLUSION

This paper proposes a novel routing protocol called Energy Constraint-Aware Routing (ECAR) for data transmission in Mobile Ad hoc Medical Care Networks. Aimed at prolonging the overall network lifetime, ECAR takes the node's energy capability, buffer capability and mobility into consideration when selecting a route. For image data, which is quite a popular type of data in MAMCN, ECAR applies a distributed compression scheme along with the route algorithm to further reduce the energy consumption on low capability nodes. Simulation results in various scenarios show that the whole design effectively increases the network lifetime compared to other routing schemes. The scheme benefits MAMCN environments by providing efficient data transmission and longer network availability.

7. REFERENCES

[1] Amit Pande, Eilwoo Baik, Prasant Mohapatra, "Efficient Health Data Compression on Mobile Devices", ACM MobileHealth 2013

[2] C．K．Toh, "Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad Hoc Networks", IEEE Communications Magazine，2001, 39(1): 138-147

[3] Debopam Acharya, Vijay Kumar, Hyo-Joo Han "Performance Evaluation of Data Intensive Mobile Healthcare Test-Bed in a 4G Environment", ACM MobileHealth 2012

[4] Huaming Wu, Alhussein A. Abouzeid, "Energy efficient distributed image compression in resource-constrained multihop wireless networks", Computer Communications 28 (2005) 1658–1668

[5] JPEG2000 Image Compression Fundamentals, Standards and Practice, David S. Taubman and Micheal W. Marcellin

[6] Laura Marie Feeney, Martin Nilsson, "Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment", IEEE InfoCom, 5(8), 2001

[7] Morteza Maleki, Karthik Dantu, Massoud Pedram, "Lifetime Prediction Routing in Mobile Ad Hoc Networks", Wireless Communications and Networking, New Orleans, FL, USA, 2003, 1 185-1 190

[8] Mohsen Nasri, Abdelhamid Helali, Halim Sghaier, Hassen Maaref, "Adaptive image compression technique for wireless sensor networks", Computers and Electrical Engineering 37 (2011) 798–810

[9] R. S. H. Istepanian, E. Jovanov, and Y. T. Zhang, "mhealth: beyond seamless mobility for global wireless healthcare connectivity-Editorial," IEEE Transaction for Information Technology in Biomedicine, Vol. 8, no. 4, pp. 405-414, Dec. 2004.

[10] Yang Liu, Robert Kelley,Phani Polina, Sunderesh Heragu, Anup Kumar "iResTrac: An Architecture for Maintaining Medical Resource Status with Mobile Devices" ACM MobileHealth 2011

[11] Y. Sun, C. Phillips, J. Bai, H. Zhang, J. Hou, S. Wang, "Cognitive Radio Mobility Based Routing Protocol for CR Enabled Mobile Ad hoc Networks", IEEE Global Communications Conference, Exhibition & Industry Forum 2013 (IEEE GLOBECOM 2013)