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A Greedy Algorithm in WSNs for Maximum Network Lifetime and Communication Reliability

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***Abstract*— A wireless sensor network (WSN) usually operates in an unreliable wireless environment with energy constraint. Many researchers are primarily interested in energy awareness and communication reliability of WSNs to maximize network lifetime. However, dealing with the conflicting problems of improving energy efficiency and fault-tolerance simultaneously is a challenging task. Most previous studies have shown that both problems can be approached by using either data link or network layer protocols. In this paper, we present a cross-layer protocol, which integrates a multipath routing protocol and a data interleaving technique based on Reed-Solomon code. We formulate the problem of selecting sensor transmission paths as a knapsack problem and solve it by a greedy algorithm. Our multipath routing protocol then enables each sensor to select multiple transmission paths using the proposed optimization algorithm. On the basis of multiple transmission paths, the technique of data interleaving is employed by using Reed-Solomon code to provide reliable data transmission. Simulation results demonstrate that our scheme outperforms the existing multipath routing protocols with respect to the network lifetime since it balances energy consumption and promotes communication reliability.**

Keywords—wireless sensor network; energy awareness; communication reliability; knapsack problem; Reed-Solomon code; interleaving technique; greedy algorithm; maximizing network lifetime.component;

I. INTRODUCTION

As the applications of WSNs become public and pervasive, numerous techniques of WSNs have recently been requested and developed [[10],[27],[35]]. These techniques include the processes of balancing energy consumption to improve network lifetime and maintaining data integrity for communication reliability. Due to the importance of WSN, many researchers have been devoted to both fields of balancing energy consumption and achieving data integrity. By maximizing network lifetime and maintaining the correctness of sensed data, ambient monitoring systems could persistently and promptly analyze the sensed data to make appropriate decisions regarding the domains concerned.

The routing protocol of a wireless network could be designed to serve different purposes, including transmission reliability [[25],[34]], congestion control [[16]**Error! Reference source not found.**], fault tolerance [[3],[27]], quality of service (QoS) [[6],[19],[32]], transmission delay minimization [[8],[15]], interference awareness [[11],[32]] and energy awareness [[5],[6],[14],[15]]. Among the existing proposals, multipath routing protocols are proposed to meet one of the purposes [[5],[11],[12],[23],[34]]. We are motivated to employ a multipath routing protocol to balance energy consumption.

In this work, we propose a novel cross-layer protocol to balance energy consumption and achieve communication reliability in WSNs. Our scheme integrates data interleaving technique [[4],[20]] with a multipath routing protocol to prolong network lifetime and achieve transmission reliability simultaneously. The interleaving technique based on the notable Reed-Solomon code [[9],[18]] operates at the physical layer to provide redundancy-based data protection. We transform an “Ad hoc On-demand Multipath Distance Vector” (or AOMDV)-inspired multipath routing protocol into a multipath routing protocol for providing fault-tolerant routing and balancing energy consumption. By improving the reliability of data transmission and providing fault-tolerant routing, our scheme can reduce data retransmission and then conserve power dissipation. We approach the problem by employing the algorithms designed for the notable knapsack problem. Our scheme first executes the modified AOMDV-inspired multipath routing protocol [[17][17]] to calculate all available paths to the sink. When a sensor node transmits sensed data, it integrates Reed-Solomon code and data interleaving for data integrity by jointly considering energy consumption and signal quality.

The remaining parts of this paper are organized as follows. The related researches are reviewed in Section 2. Notation used in this paper is defined in Section 3. Section 4 presents a multipath routing algorithm for maximum network lifetime and communication reliability. Performance evaluation is provided in section 5. Finally, Section 6 concludes this work and outlines some plans for future development.

II. REVIEW OF THE RELATED APPROACH

A. Related AOMDV Protocol Selecting

The AOMDV protocol was proposed by Marina and Das to discovery multiple paths in an ad-hoc network [[24]]. AOMDV is a multipath version derived from AODV, a single-path routing protocol [[30]]. AOMDV consists of two phases. In the first phase, multiple loop-free reverse paths from destination to source sensor nodes are discovered by transmitting route-request (RREQ) messages. Since there could be many discovered paths in this phase to result in diminishing effectiveness [[28]], the second phase selects useful link disjoint paths. There are link and node disjoint paths. The node-disjoint paths only discovered a few paths in a dense network using flood, but link-disjoint paths are opponent. Therefore, AOMDV discover the link-disjoint paths are a good solution. However AOMDV does not consider any mechanism of load distribution for splitting network traffic over the discovered paths. AOMDV-inspired multipath routing protocol [[17][17]] uses different strategy of routing table management. While AOMDV finds all the possible link-disjoint paths between each sensor node and the sink node optimized for hop counts, AOMDV-inspired multipath routing protocol reduces the transmission delay and interference by requiring all the sensor nodes to retrieve the timing information of their neighboring nodes. It also provides the mechanism of load distribution. In the procedure of data transmission, each relay node searches its routing table and forwards packets to the next hop awakening nodes.

B. Reed-Solomon Code

Currently, error control techniques can be classified into two types: forward error correction (FEC) and automatic repeater quest (ARQ). Although both techniques can guarantee the transmission reliability, ARQ usually consumes more energy under a heavily-interference circumstance. FEC has the ability of self correction by using the error correction code. By sending the data along with the redundant bits over the transmitted channel, the receiver can correct the error bits under a limited fashion. Since a wireless sensor network usually operates in an energy constraint and unreliable wireless environment. ARQ method may suffer from unreliable energy efficiency. We prefer the FEC method that employs Reed-Solomon (RS) codes invented by Reed and Solomon [[18]**Error! Reference source not found.**]. RS codes is a non-binary cyclic error-correcting code used in communication systems to resist the random error. The Reed–Solomon codes is a linear block code of length n over the finite field F with k dimensions, where the minimum Hamming distance between any two RS codes is $n - k + 1$. Thus, RS codes is a $[n, k, n - k + 1]$ code. Formally, the set A of codewords of the Reed–Solomon code is defined as follows:

$$A = \{(f(x_1), f(x_2), \ldots, f(x_n)) \mid f \in F(x), deg(f) < k\}, for\ 1 \leqq k \leqq n \leqq |F|$$

TABLE 1. THE PARAMETER AND ITS DESCRIPTION FOR REED–SOLOMON CODE

Parameter	Description
m	Symbol width (unit of RS), where *n*m* is the amount of coded data.
n	Codeword length, where *n*m* is the amount of coded data.
k	The number of information symbol.
t=(n-k)/2 or n-k	The number of maximum correctable symbols. If the error position cannot be predicted, RS code can correct up to (n-k) / 2 errors; otherwise, it can correct up to n-k errors.
*t*m*	The number of error-correcting codes.

C. Packet Interleaving Technique

Interleaving is a technique widely used in storage systems and digital communication. It can be combined with forward error correcting codes to improve the performance of error correction. In a heavily interference environment, transmission errors usually occur not independently but consecutively in burst. Packet interleaving alleviates this problem by mingling source symbols across several code words stored in different packets to create a uniform distribution of errors [[4],[20]].

D. Knapsack problem

Knapsack problem is a combinatorial optimization problem first proposed by Mathews in 1897 [[26]]. Let there be n items, I_i, where $1 \leqq i \leqq n$. Each item I_i has a benefits b_i and weight w_i. The maximum weight that we can carry in the knapsack is W. The knapsack problem determines the number of each items in a collection so that the total weight is less than or equal to a given W with the largest total benefit. Aiming at different applications, the knapsack problem has been derived into different problems, including 0-1 knapsack problem, bounded knapsack problem (BKP), unbounded knapsack problem (UKP), fractional knapsack problem (FKP) and so on[[1],[2],[7],[13],[21],[22],[29],[31],[33]].

III. PROBLEM AND NOTATION DEFINITION

Our scheme requires that before a sensor node transmits data, it needs multiple paths by executing our modified AOMDV-inspired multipath routing protocol. Next, the transmitted data is split over multiple paths by using interleaving and Reed-Solomon code. This process derives a data assignment problem, which jointly considers residual energy, bit error rate, and reliability simultaneously. We attempt to maximize the lifetime of sensor nodes while maintaining the data reliability. We list the notations used in this paper as below.

L: the total number of bits of the sensed data;

B: the maximum number of error bits that can be recovered by Reed-Solomon code;

n: the total number of paths;

c_i*: the number of hop counts on the i-th path,* $1 \leqq i \leqq n$*;*

$\hat{e}_{res_{ij}}$*: the residual energy of j-th node on the i-th path,* $1 \leqq j \leqq c_i$*,* $1 \leqq i \leqq n$*;*

dij: the distance between j-th node and j+1-th node on the i-th path, $1 \leqq j \leqq c_i-1$*,* $1 \leqq i \leqq n$*;*

l_i*: the number of bits of the sensed data transmitted through the i-th path,* $1 \leq i \leq n$*;*

$E_{Tx}(d_{ij})$*: the energy consumption of transmitting one-bit sensed data to the j+1-th node of the i-th path,* $1 \leqq j \leqq c_i-1$*,* $1 \leqq i \leqq n$*;*

E_{Rx}*: the energy consumption when a node receives one-bit sensed data;*

e_{ij}: the energy consumption of one-bit sensed data is transmitted and received of the j-th node on i-th path. Formally, the e_{ij} is defined as follows:

$$e_{ij}\begin{cases} e_{i1}=E_{Tx}(d_{i1}),\ for\ 1\leq i\leq n,\ j=1; \\ e_{ic_i}=E_{Rx},\ for\ 1\leq i\leq n,\ j=c_i; \\ e_{ij}=E_{Rx}+E_{Tx}(d_{ij}),\ for\ \ 1\leq i\leq n,\ 2\leq j\leq c_i-1. \end{cases}$$

The first sensor node only transmits sensed data, the energy consumption is $e_{i1}=E_{Tx}(d_{i1})$ and the sink only receives sensed data, the energy consumption is $e_{ic_i}=E_{Rx}$. Otherwise mid-nodes need to receive and transmit sensed data, the energy consumption is $e_{ij}=E_{Rx}+E_{Tx}(d_{ij})$.

E_i: the energy consumption of one-bit sensed data is transmitted and received on the i-th path, $1\leq i\leq n$, $E_i=\sum_{j=1}^{j=c_i} e_{ij}$;

S: noise spectral density in the WSN;

β_i: bit error rate of the i-th path, $1\leq i\leq n$, $\beta_i=\sum_{j=1}^{j=c_i} e_{ij}$;

We formulate the problem of splitting the sensed data to multiple packets as follows. Each packet takes different paths, while maximizing the lifetime of the sensor nodes.

(Output) m_i: Optimal data chunk size on the i-th path, $1\leq i\leq n$,

There are three constraints in this problem.

1. $\sum_{i=1}^{i=n} m_i$
2. $\sum_{i=1}^{i=n} m_i\beta_i \leq B$
3. $m_i e_{ij} \leq \hat{e}_{re_{ij}},\ for\ 1\leq i\leq n, 1\leq j\leq c_i$

The problem of assigning the sensed data into different paths while achieving communication reliability and extending network can be formulated as a bounded knapsack problem, which can be approached by using greedy algorithm. We show how the data assignment problem is transformed to the knapsack problem in Table 2. The notations are listed below.

TABLE 2. MAPPING OF THE DATA ASSIGNMENT PROBLEM TO THE KNAPSACK PROBLEM

	Knapsack Prblem	**Data assignment problem**
Input1	A knapsack with weight *W*>0	A sensor node with sensed data *L*>0
Input2	*n* items (*Ii*) with weights *wi* > 0, benefits *bi* > 0 and bounded number of items *Mi > 0,for i =1, 2 ..,n*	*n* paths *(Pi)* with basic unit of digital communication l_i = 1, residual energy $re_i = min\left[\hat{e}_{re_{ij}}\right] > 0$, *for j=1,2,..., Ci , for i =1, 2 ..,n* and bounded number of transmitted bits $M_i - min\left[{}^{B_i}/_{\beta_i}, {}^{re_i}/_{E_i}\right] > 0$, *for i =1, 2 ..,n*
Output	Optimal number of I_i can be placed in a backpack, *mi*	Optimal data chunk size on the P_i can be sent sensed data, m_i
Purpose	$max\sum_{i=1}^{n} m_i \times b_i$	$\max_{1\leq i\leq n}\left\{\min_{1\leq j\leq c_j}\left[\hat{e}_{re_{ij}}\right]\right\}$
subject to	$m_i \leq M_i$ $\sum_{i=1}^{n} m_i \times w_i \leq W$	$m_i \leq M_i$ $\sum_{i=1}^{n} m_i \times l_i - \sum_{i=1}^{n} m_i - L$ $\sum_{i=1}^{n} B_i \leq B$

re_i: the residual energy on i-th path is the lowest residual energy which j-th nodes, for $1\leqq j\leqq c_i$. $re_i = \min[\hat{e}_{re_{ij}}]$ $1\leqq j\leqq c_i$, $1\leqq i\leqq n$;

B_i/β_i: the bounded number of transmitted bits on i-th path which the limits of max error bits and error bit rate, $1\leqq i\leqq n$;

re_i/E_i: the bounded number of transmitted bits on i-th path which the limits of residual energy and energy consumption rate, $1\leqq i\leqq n$;

M_i: the bounded number of transmitted bits on i-th path which the limits of energy and error bit, $M_i = min[\frac{B_i}{\beta_i},\frac{re_i}{E_i}]$, $1\leqq i\leqq n$;

IV. THE PROPOSED SCHEME

The proposed cross-layer protocol uses the modified AOMDV-inspired multipath routing protocol to generate multiple paths for the sensor nodes without routes to the sink node in their routing tables. The modified AOMDV-inspired multipath routing protocol generates *n* paths, where *n* denotes the number of paths from the sensor node to the sink node. Some of the *n* paths are then selected for data transmission. The sensed data is divided into multiple parts so that each part is transmitted by a unique path. Each part of the sensed data is converted to block-based error correction codes using Reed-Solomon code. The data interleaving aims at balancing energy consumption while maintaining the data correctness from burst errors. As mentioned above, we map the problem of slicing data into multiple pieces to a bounded knapsack problem. We use greedy algorithm to approach this problem.

We begin with the proposed routing protocol. Our protocol is based on the AOMDV-inspired multipath routing protocol by modifying the mechanism of load distribution, but retaining the mechanism of optimal link-disjoint paths for availability. The paths generated by our protocol have disjoint nodes to balance the energy consumption. In addition, we also avoid using the long paths because each packet relay causes energy consumption. In the following, we describe the proposed routing protocol stepwise.

A. The routing protocol for generating multiple paths

INPUT: A wireless sensor network with at least one sink and multiple sensor nodes.

OUTPUT: A set of paths from a sensor node to the sink node.

STEP 1: When a route is needed, source node broadcasts a route-request message (RREQ) for acquiring paths to the sink node.

STEP 2: When a node receives a RREQ, it checks the advertised hop count of send node of this message. If the answer is lesser than received node's, then a reverse path to the original sensor node is yielded. Else if the answer is equal, then checks the id of send node, if the answer is bigger than received node's.

Then a reverse path to the original sensor node is yielded. Otherwise, ignores the message.

STEP 3: The route-request message is broadcasted once. Both STEPs 2 to 3 are repeated until the message is received by the sink node.

STEP 4: When the sink node receives a route-request message, multipath from the sensor to the sink node is generated. These paths information is stored in the routing table of every node. In the routing table, there is a lot of paths information as destination, next hop, last hop, Ei, ßi, rei. These paths information in response to the reverse path is entrained in the STEP 2. These sensor nodes only reserve the link-disjoint paths by checking whether the next-hop and the last-hop sensor nodes are unique.

STEP 5: After generating multiple link-disjoint paths, we use the paths whose length is shorter than the average path length of all paths for data transmission and the rest are reserved for availability.

When the set of paths is generated, the sensor node is ready to transmit data. In addition to generate packet route to the sink node, the routing protocol also gathers the path information, including the residual energy of each node, the bit error rate and transmission energy of each hop. Accordingly, the original sensor node can calculate the residual energy, energy consumption and bit error rate of each path. Next, we present two methods to calculate the optimal data assignment for maximizing the network lifetime. As mentioned above, we have mapped the data assignment problem to the fractional knapsack problem. The proposed greedy algorithm is described as follows.

B. The Greedy Algorithm for data assignment

INPUT: Data for transmission L of a sensor node, whose routing table has a set of *n* paths, P_i, to the sink node, $1 \leqq i \leqq n$. P_i has residual energy re_i, energy consumption rate E_i, *bit* error rate β_i .

OUTPUT: Optimal data chunk size m_i for the *i*-th path, $1 \leqq i \leqq n$.

STEP 1: Sort the paths in a descending order of the value re_i / E_i (the bounded number of transmitted bits on the *i*-th path which is limited by residual energy and energy consumption rate), where $1 \leq i \leq n$.

STEP 2: Set $i=1$, where *i* denotes the number of paths used for data transmission.

STEP 3: Check whether the value *L* is equal to 0. If the answer is positive, then the algorithm ceases. Otherwise, it proceeds to the next step.

STEP 4: Check whether the value $\sum_{a=i}^{a=n} M_i$ is less than *L*. If $\sum_{a=i}^{a=n} M_i$ is less than *L*, then the algorithm ceases because the energy or data error rates of the unused paths are not enough for transmitting the *l*-size data. Otherwise, the algorithm proceeds to the next step.

$$\sum_{a=i}^{a=n} M_i < L;$$

STEP 5: Set $m_i=M_i$, where m_i is the maximum allowable number of transmitted bits on the current path.

STEP 6: If m_i is less than or equal to *L*, then we set $i=i+1, L=L-m_i$ and repeat STEPs 3 to 6. Otherwise, we set $m_i=L$, $i=i+1, L=L-m_i$ and repeat STEPs 3 to 6.

The greedy algorithm determines the paths for data chunk transmission. Before starting transmission, the Reed-Solomon code and interleaving technique are applied to the data chunks for communication reliability. The following flowchart illustrates how Reed-Solomon code and interleaving technique are used in this paper. By encoding the original data using the Reed-Solomon code, all data chunks are then interleaved by transmitting them over different paths based on the previous calculation. After these interleaved data chunks are received by the sink node, they are merged and decoded their Reed-Solomon codes to recover the original data.

V. EXPERIMENT

In this paper, a framework has been proposed for maximizing network lifetime while maintaining communication reliability in a WSN. We evaluate the performance of the proposed framework. We also relate our framework with two previous routing protocols, AOMDV and AOMDV-inspired multipath routing protocol. All protocols are implemented using C++ carried on a laptop with Intel Core i5-4200U 1.60GHz CPU. Three different WSN grid topologies are used in the evaluation, where the number of sensor nodes in each WSN is 48(7*7), 120(11*11) or 223(15*15). In the smaller two WSNs, there is only one sink node while the largest WSN has two sink nodes. These grid topologies, in which the distance between nodes is 1 meter. The sink positions in intermediate of grid topology. The communication radius of node is 2 meters. The amount of energy consumption for communicating with different nodes within the radio range is listed in Table 3.

TABLE 3. POWER CONSUMPTION

Distance	Action	Amount of energy
1 meter	send	0.1
	receive	0.05
1.5 meters	send	0.2
	receive	0.1
2 meters	send	0.3
	receive	0.15

The first experiment shows the relationships between the network lifetime and the initial energy capacity for different routing protocols. The network lifetime is measured in a cycle that each sensor node transmits 100 bits to the sink node, until the remaining energy of any one sensor node cannot send any further packet. The results of 120 sensor nodes are shown in Figure 1. The results show that the number of network lifetime cycles increases along with the increasing initial energy capacity, which is consistent with our intuition. The proposed greedy algorithm outperform both AOMDV and AOMDV-inspired multipath routing protocol, regardless the initial energy capacity. Our algorithm achieves better performance for two reasons. First, we use Reed-Solomon code for maintaining transmission reliability. In spite of the overhead of Reed-Solomon code, our algorithms avoid packet retransmission to reduce overall energy wastage. Second, our routing algorithms balance energy consumption of a WSN by adaptively transmitting data over multiple paths. As a result, each node could transmit more data by extending the lifetime of a WSN.

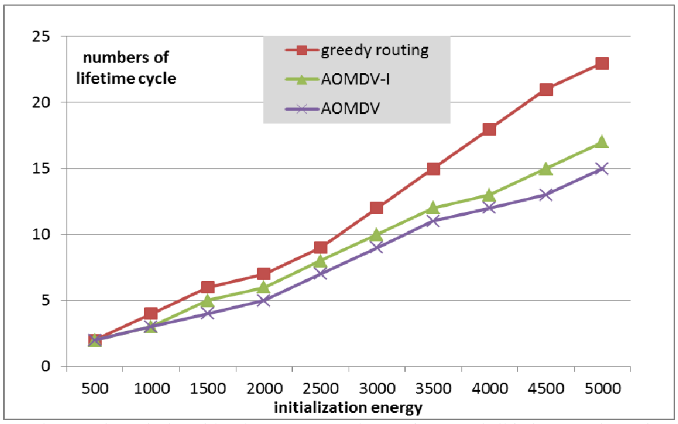

Fig. 1. The relationships between numbers of network lifetime cycle and initialization energy along with different routing protocols.

Next experiments consider the relationships between the numbers of network lifetime cycles and initial energy capacity using three different topologies. We show the results of the greedy algorithm in Figure 2, respectively. In this figures, it is obvious that the network lifetime increases along with the increasing initial energy capacity. Our algorithm can be successfully executed in WSNs of different sizes. Also, the results from our first and third topologies are higher than those of the second topology, indicating that the maximum network lifetime is closely related to the routing protocol and the numbers of sensor or sink nodes.

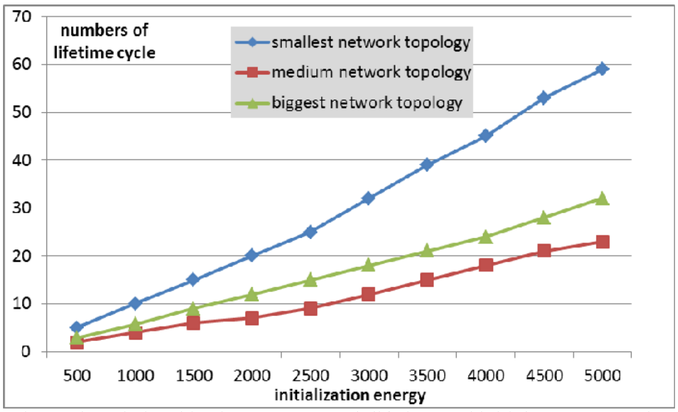

Fig. 2.The relationships between network lifetime and initial energy capacity for three different topologies using our routing protocol with a greedy algorithm

VI. CONCLUSION

In this paper, we have proposed a novel cross-layer framework including a multipath routing protocol and a packet interleaving technique based on Reed-Solomon code. By distributing the sensed data to multiple paths, the energy consumption of each sensor node can be balanced to prolong network lifetime. We present a greedy algorithm of assigning data chunks to different paths. The employment of Reed-Solomon code also ensures the communication reliability to avoid packet retransmission. As a result, the network lifetime can be extended as shown in the experimental results. In our future work, we will jointly consider TDMA schedule to improve overall energy efficiency of a WSN.

REFERENCES

[1] A.L. Olsen. Genetic Algorithms and the Knapsack Problem: A Study of Penalty Functions. Masters thesis, University of North Carolina at Charlotte, 1993.

[2] A.L. Olsen. Penalty functions and the knapsack problem. In Proceedings of the First IEEE Conference on Evolutionary Computation, Orlando, Florida, June 1994. IEEE Press. pp. 554-558.

[3] Alwan, H.; Agarwal, A. A Survey on Fault Tolerant Routing Techniques in Wireless Sensor Networks. In Proceedings of the 3th International Conference on Sensor Technologies and Applications (Senosrcomm '09), Athens, Greece, 18–23 June 2009; pp. 366–371

[4] B. Vucetic, J. Yuan (2000). Turbo codes: principles and applications. Springer Verlag. ISBN 978-0-7923-7868-6

[5] Bagula, A.; Mazandu, K. Energy Constrained Multipath Routing in Wireless Sensor Networks. In Proceeding of the 5th International Conference on Ubiquitous Intelligence and Computing, Oslo, Norway, 23–25 June 2008; pp. 453–467.

[6] Ben-Othman, J.; Yahya, B. Energy Efficient and QoS Based Routing Protocol for Wireless Sensor Networks. J. Parall. Distrib. Comput. 2010, 70, 849–857.

[7] Dantzig, George B. (1957), "Discrete-variable extremum problems", Operations Research 5: 266–277, doi:10.1287/opre.5.2.266, MR 0089098.

[8] Dezfouli, B.; Radi, M.; AbdRazak, S. A Cross-Layer Approach for Minimizing Interference and Latency of Medium Access in Wireless Sensor Networks. Int. J. Comput. Netw. Commun. 2010, 2, 126–142.

[9] F. J. MacWilliams and N. J. A. Sloane, The Theory of Error-Correcting Code, New York: North-Holland Publishing Company, 1977.

[10] Fonseca, R.; Gnawali, O.; Jamieson, K.; Levis, P. Four-Bit Wireless Link Estimation. In Proceedings of the 6th Workshop on Hot Topics in Networks (HotNetsVI), Atlanta, GA, USA, 14 November 2007.

[11] Fu, B.; Li, R.; Xiao, X.; Liu, C.; Yang, Q. Non-Interfering Multipath Geographic Routing for Wireless Multimedia Sensor Networks. In Proceedings of the International Conference on Multimedia Information Networking and Security, Wuhan, China, 18–20 November 2009; pp. 254–258.

[12] Gallardo, J.R.; Gonzalez, A.; Villasenor-Gonzalez, L.; Sanchez, J. Multipath Routing Using Generalized Load Sharing for Wireless Sensor Networks. In Proceeding of the International Conferences on Wireless and Optical Communications, Montreal, QC, Canada, 30 May–1 June 2007.

[13] Goodrich, Michael T., Tamassia, Roberto (2002), "5.1.1 The Fractional Knapsack Problem", Algorithm Design: Foundations, Analysis, and Internet Examples, John Wiley & Sons, pp. 259–260.

[14] Hassanein, H.; Luo, J. Reliable Energy Aware Routing in Wireless Sensor Networks. In Proceedings of 2nd IEEE Workshop on Dependability and Security in Sensor Networks and Systems, Los Alamitos, CA, USA, 24–28 April 2006; pp. 54–64.

[15] He, L. Delay-Minimum Energy-Aware Routing Protocol (DERP) for Wireless Sensor Networks. In Proceedings of the International Conference on Software Engineering, Artificial Intelligence,

Networking, and Parallel/Distributed Computing (SNPD ’07), Qingdao, China, 30 July–1 August 2007; Volume 3, pp. 155–160.

[16] He, T.; Ren, F.; Lin, C.; Das, S. Alleviating Congestion Using Traffic-Aware Dynamic Routing in Wireless Sensor Networks. In Proceedings of the 5th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON ’08), San Francisco, CA, USA, 16–20 June 2008; pp. 233–241. Sensors 2012, 12 683

[17] Hurni, P.; Braun, T. Energy-Efficient Multi-Path Routing in Wireless Sensor Networks. In Proceedings of the 7th International Conference on Ad-Hoc, Mobile and Wireless Networks (ADHOC-NOW ’08), Sophia Antipolis, France, 10–13 September 2008; pp. 72–85.

[18] Reed, Irving S.; Solomon, Gustave (1960), Polynomial Codes over Certain Finite Fields, Journal of the Society for Industrial and Applied Mathematics (SIAM) 8 (2): 300–304, doi:10.1137/0108018

[19] Jaswant Kumar Joshi*, Devendra Singh Bais,AmarNathDubey, Analyzing Video Streaming Quality over Different Routing Protocols on Mobile Ad-hoc Network, International Journal of Advanced Research in Computer Science and Software Engineering, Volume 3, Issue 10, October 2013, ISSN: 2277 128X.

[20] K. Andrews et al. (November 2007). "The Development of Turbo and LDPC Codes for Deep-Space Applications". Proc. of the IEEE 95 (11).

[21] Korte, Bernhard; Vygen, Jens (2012), "17.1 Fractional Knapsack and Weighted Median", Combinatorial Optimization: Theory and Algorithms, Algorithms and Combinatorics 21, Springer, pp. 459–461, ISBN 9783642244889.

[22] Kuk-Hyun Han, Jong-Hwan Kim. Genetic Quantum Algorithm and its Application to Combinatorial Optimization Problem. Evolutionary Computation. Proceedings of the 2000 Congress, Pages1354 - 1360 vol.2,Jul 2000.

[23] Li, S.; Neelisetti, R.K.; Liu, C.; Lim, A. Efficient Multi-Path protocol for Wireless Sensor Networks. Int. J. Wirel. Mobile Netw. 2010, 2, 110–130.

[24] Mahesh Marina, Samir Das. Ad Hoc On-demand Multipath Distance Vector Routing ,In Wiley Wireless Communications and Mobile Computing (WCMC) Journal Special Issue on Wireless Ad hoc Networks: Technologies and Challenges, Vol. 6, No. 7, pp. 969-988, Nov 2006. An earlier version appeared in Proc. IEEE ICNP, Riverside, USA, Nov 2001.

[25] Marjan Radi, Behnam Dezfouli, Kamalrulnizam Abu Bakar and Malrey Lee, Multipath Routing in Wireless Sensor Networks: Survey and Research Challenges, Sensors 2012, 12, 650-685; doi:10.3390/s120100650.

[26] Mathews, G. B. (25 June 1897). "On the partition of numbers". Proceedings of the London Mathematical Society 28: 486–490.

[27] Mohamed Younis, Izzet F. Senturk, Kemal Akkaya, Sookyoung Lee, Fatih Senel, Topology management techniques for tolerating node failures in wireless sensor networks: A survey, Computer Networks 58 (2014) 254–283.

[28] Nasipuri A, Castaneda R, Das SR. Performance of multipath routing for on-demand protocols in mobile ad hoc networks ACM/Kluwer Mobile Networks and Applications (MONET)2001; 6(4): 339−349

[29] Oscar H. Ibarra; Chul E. Kim. Fast Approximation Algorithms for the Knapsack and Sum of Subset Problems. Journal of the ACM (JACM) Volume 22 Issue 4, Oct. 1975, Pages 463-468.

[30] Perkins, C.E., M. Belding-Royer E.: Ad hoc On-Demand Distance Vector (AODV) Routing, RFC 3561, 2003

[31] R. Hinterding. Representation, Constraint Satisfaction and the Knapsack Problem, in Proceedings of the 1999 Congress on Evolutionary Computation, pp. 1286-1292, Jul 1999.

[32] Radi, M.; Dezfouli, B.; Bakar, K.A.; AbdRazak, S.; Nematbakhsh, M.A. Interference-Aware Multipath Routing Protocol for QoS Improvement in Event-Driven Wireless Sensor Networks. Tsinghua Sci. Tech. 2011, 16, 475–490.

[33] S. Martello and P. Toth. Knapsack Problems. John Wiley & Sons, 1990.

[34] Tarique, M.; Tepe, K.E.; Adibi, S.; Erfani, S. Survey of Multipath Routing Protocols for Mobile Ad Hoc Networks. J. Netw. Comput. Appl. 2009, 32, 1125–1143.

[35] Tarn, W.H.; Tseng, Y.C. Joint Multi-Channel Link Layer and Multi-Path Routing Design for Wireless Mesh Networks. In Proceedings of the 26th IEEE International Conference on Computer Communications (INFOCOM ’07), Anchorage, AK, USA, 6–12 May 2007; pp. 2081–2089. Sensors 2012, 12 684.