Quality-Driven Energy-Neutralized Power and Relay Selection for Smart Grid Wireless Multimedia Sensor Based IoTs

Runan Yao, Student Member, IEEE, Wei Wang, Member, IEEE, Mahdi Farrokh-Baroughi, Member, IEEE, Honggang Wang, Senior Member, IEEE, Yi Qian, Senior Member, IEEE

Abstract—With the popularity of photovoltaic based green energy in smart grid systems, accurate information gathering becomes a critical issue in predicting micro grid power input. In this paper we proposed a new quality-optimized multimedia information gathering scheme, in Energy Harvesting Wireless Sensor Networks (EHWSN) base Internet of Things (IoTs) system, to provide the best-effort sky camera information accuracy for further predicting available photovoltaic power. In the proposed approach, the power control and relay node selection strategies are jointly optimized to achieve maximum sky camera image quality subject to the harvestable energy neutrality constraint. Simulation results show that the proposed scheme can improve multimedia data transmission quality by exploring adaptive transmission power and relay selection strategy.

Index Terms—smart grid, energy harvesting wireless sensor network, power control

I. INTRODUCTION

Green energy technologies such as photovoltaic (PV) have attracted considerable attention in smart grid systems due to their harmonious relationships with nature, their green impact on the global environment, and their sustainability. Despite these desirable characteristics, PV solar source is time-varying energy that exhibits completely random power generation patterns and goes through extreme fluctuations. Thus, smart grid has a strong requirement of predicting harvestable energy inputs in upcoming time frames. An Internet of Things (IoTs) sky image gathering system based on Energy Harvesting Wireless Sensor Network (EHWSN) for smart grid PV power estimation is demonstrated in Figure 1. In this figure, cloud coverage images can be caught by the sky cameras and transmitted to a centralized server, where the sky images will be analyzed to estimate the future available PV power in the smart grid system. Such estimation will eventually lead to optimized decisions on dispatching power flows in the smart grid system. In such an EHWSN/IoTs sky image gathering system, energy supply is not only extremely limited but also temporally fluctuating. On the other hand, there is a strong requirement of the gathered sky cloud image quality at the server side. Thus how to provide sky image transmission quality with limited and fluctuating EHWSN/IoTs energy inputs becomes a critical challenge.

In this paper we propose a new quality-driven energy-neutralized power and relay selection framework to improve the sky image gathering quality in smart grid EHWSN/IoTs. The major contribution of the proposed approach lies in two folds. First, the proposed EHWSN/IoTs relay and power control protocol is designed adaptive to environmental harvestable energy input. Second, the difference of importance levels of various sky image packets is explored at lower layer of the protocol stacks, where the power and relay selection strategy is optimized according to both multimedia packet unequal importance and wireless channel environments.

Research works on EHWSN/IoTs quality data gathering for power estimation in smart grid have rarely been reported. On the smart grid energy dispatching optimization side, [1] proposed an intelligent dispatching approach to allocate renewable energy in a smart grid by incorporating an energy storage device. In [2], a priority-based traffic scheduling approach was proposed to enhance the performance of Cognitive Radio (CR) communication infrastructure to support real-time communication in a smart grid. It classified and prioritized different traffic types used in a CR network system, to obtain optimal resource utilization. In research [3], the authors proposed a find reliable link approach to provide low latency sensor communications for smart grid with distributed generators. Through sensor network data aggregation, smart grid system reliability and operation accuracy could be improved. In research [4], a PV power output forecasting model was proposed based on weather forecast data and a support vector machine, and similar green power predictors in smart grid have been reported in [18] [19]. Recent survey reported in [21] discussed new challenges and opportunities in smart grid wireless communications. The coordinated standardization efforts in Europe were also discussed illustrating new directions in industrial technology adoption. Similar research in [22] identified three major challenges to implement smart grid communication systems: standards interoperability, cognitive access to unlicensed radio spectra, and cyber security. Research in [23] presented solutions to design, implement and integrate communication infrastructures with existing power systems. A case study of a smart grid demonstration project, the Future Renewable Electric Energy Delivery and Management (FREEDM) system was performed, and real-world implementation and performance evaluation.
were conducted. On the network cooperate optimization side, [9] proposed an algorithm to determine whether a data packet needs to be relayed or not in an energy harvesting wireless environment. Considering what the information states, a solution can be easily reached if node positions are fixed. In [12], the authors proposed Markov Decision Process (MDP) and Partially Observable Markov Decision Process (POMDP) algorithms to extend the life of an EHWSN/IoTs, by considering the characteristics of the energy harvesting. They approached a longer system lifetime by optimizing the schedule in a fixed transmission power system. Research in [5] presented an adaptive duty cycling algorithm to achieve efficient energy utilization. In [6], the authors proposed a neural network dynamics optimization framework which improved sensor network lifetime. Without using centralized computing nodes, that solution provided higher system reliability. Many other similar research works also stated the design of WSN in a new way based on the natural energy harvesting [7] [16] [17]. Some other studies were focusing on the node sleep/wakeup timing control [8] and sensor hardware improvement [13]. Our preliminary research in [14] [15] focused on investigating the adaptability of a communication protocol to energy harvesting profiles. In [14], a link level network Automatic Repeat reQuest (ARQ) retransmission limit adaptation algorithm was proposed to minimize the cumulative average packet error rate based upon environmental energy availability. In [15], we adopt the EHWSN/IoTs source coding rate to the estimated harvestable energy resource, to optimize the per hop data gathering quality.

Fundamentally different from existing research, in this paper we focus on how to accurately gather sky camera multimedia information through energy harvesting relay nodes for further smart grid PV energy prediction. Specifically, we optimize the transmission power and relay selection strategy adapting it to both energy harvesting profiles and multimedia data content.

The rest of this paper is organized as follows. In Section II, the reliable data gathering problem is mathematically formulated. In Section III, we analyze and simplify the problem. In Section IV, the communication protocol, data gathering and optimal scheduling policy are presented. In Section V, we show numerical simulation results and in Section VI we draw conclusion.

![Fig. 1. An illustration of sky camera EHWSN/IoTs system for smart grid PV power estimation](image)

# II. PROBLEM STATEMENT

The smart grid with PV energy sources needs accurate sky camera multimedia information (e.g. cloud coverage, cloud motion estimation, etc) to estimate available solar power for the near future. In order to provide reliable multimedia data gathering in a PV smart grid system, we propose a joint power and relay control approach in underlying EHWSN/IoTs communication protocol. For each data packet transferred in EHWSN/IoTs, there are a set of nodes determining the forwarding path to go through. By joint power and relay optimization, our objective function is to achieve maximum distortion reduction by consuming limited energy.

The goal is to maximize the overall sky-camera image transmission quality subject to total energy consumption constraint. The main approaches are to optimally adjust transmission power and to select optimal relay node for each source. Let $P_t$ denote the transmission power selection vector, $P_{Dh}$ denote the relay node selection vector, and $E[\mathbf{D}]$ denote the distortion reduction expectation at the receiver end. The overall problem can be mathematically formulated as a relay node and relay power selection problem with energy budget constraint:

$$\left\{ P_t, S_{Dh} \right\} = \text{arg max} \{ E[D] \}$$

s.t.

$$\sum_{t} E \leq E_{\text{max}}$$

To solve this problem we will find the solution vectors for both power and relay selection that maximizes the expected distortion reduction of smart grid sky camera images, while satisfying the energy constraint in the EHWSN/IoTs.

### TABLE I

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_t$</td>
<td>transmission power selection vector</td>
</tr>
<tr>
<td>$S_{Dh}$</td>
<td>relay node selection vector</td>
</tr>
<tr>
<td>$E[\mathbf{D}]$</td>
<td>distortion reduction expectation</td>
</tr>
<tr>
<td>$E$</td>
<td>total energy consumption estimation</td>
</tr>
<tr>
<td>$E_{\text{max}}$</td>
<td>maximum energy consumption budget</td>
</tr>
<tr>
<td>$P_t(h, t)$</td>
<td>harvestable power for node $h$</td>
</tr>
<tr>
<td>$E_r(h, t_0)$</td>
<td>remaining energy at $t_0$ for node $h$</td>
</tr>
<tr>
<td>$E(h, t_0, t_1)$</td>
<td>available energy during $t_0$ to $t_1$ for node $h$</td>
</tr>
<tr>
<td>$E_{\text{trans}}(j, h)$</td>
<td>transmission energy cost of data packet $j$ to node $h$</td>
</tr>
<tr>
<td>$E_{\text{cons}}(h)$</td>
<td>energy consumption of a certain node $h$</td>
</tr>
<tr>
<td>$\rho_j$</td>
<td>overall transmission packet loss rate for data packet $j$</td>
</tr>
<tr>
<td>$D_j$</td>
<td>distortion reduction contribution of data packet $j$</td>
</tr>
<tr>
<td>$d$</td>
<td>Communication distance between nodes</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>wavelength of carrier</td>
</tr>
<tr>
<td>$A$</td>
<td>wireless channel signal attenuation</td>
</tr>
<tr>
<td>$e$</td>
<td>wireless channel bit error rate</td>
</tr>
<tr>
<td>$Rs$</td>
<td>symbol rate</td>
</tr>
<tr>
<td>$N_0$</td>
<td>noise power density ratio</td>
</tr>
</tbody>
</table>

Copyright (c) 2013 IEEE. Personal use is permitted. For any other purposes, permission must be obtained from the IEEE by emailing pubs-permissions@ieee.org.
III. ENERGY NEUTRALIZED QUALITY OPTIMIZATION

In the smart grid PV power prediction system, each sensor node has different data packets with various distortion reduction importance (i.e., different packets of sky camera cloud motion data) and each data packet has different transmission strategy choices (e.g., we specifically consider power control and relay selection).

We reasonably assume that we are solving the accurate data gathering problem in a small scale smart grid (i.e., a micro-grid) system. In such a small smart grid system, the PV power input could be one of the major energy sources other than electricity from traditional coal or waterfall based generators, and thus the accurate estimation of future available PV power is essentially important. In such a small smart grid system with limited PV solar farm geographic areas we also reasonably assume the multimedia packet can reach the destination using one hop relay. The proposed methodology can be seamlessly extended to any hop data gathering relays in small smart grid PV power prediction. We also assume that the wireless channel has slow fading and thus during one optimization period the channel status remains the same. To solve this optimization problem, we need to build the connection between expected distortion reduction of sky camera images, sensor network transmission energy consumption, and energy harvesting capability of the EHWSN/IoTs.

For a specific node $h$, let $P_s(h,t)$ denote the output power of the energy harvesting component, and $E_r(h,t_0)$ denote the remaining power in the rechargeable battery. Then the available power for this node during $t_0$ to $t_1$ can be expressed as:

$$E(h,t_0,t_1) = \int_{t_0}^{t_1} P_s(h,t)dt + E_r(h,t_0)$$

(3)

Let $R_j = \{h_i\}$ denote the set of nodes along the relay path of a successfully transmitted sky image data packet, $E_t(j,h_i)$ denote the energy cost of transmitting image data packet $j$ on the $h_i$ hop. The energy consumption of this node $h$ can be expressed as:

$$E_{asn}(h) = \sum E_t(j,h)$$

(4)

Let $\rho_j$ denote the overall transmission packet loss rate for data packet $j$, and let $D_j$ denote the distortion reduction contribution value of the data packet. The overall quality expectation can be formulated as:

$$D_{total} = \sum \rho_j \times D_j$$

(5)

Then the overall problem can be equivalently translated to maximize $D_{total}$ for the time period from $t_0$ to $t_1$, subject to the overall solar energy influx:

$$E_{asn}(h) \leq E(h,t_0,t_1)$$

(6)

IV. ENERGY NEUTRALIZED RESOURCE ALLOCATION

In the small scale smart grid sky camera data gathering system with slow channel fading, the channel Bit Error Rate (BER) is primarily impacted by the transmission power and the distance between transmitter and receiver. Let $d$ denote the distance and $\lambda$ denote the carrier wavelength, then the signal loss of the system can be approximated as follows.

$$A^{-1} = \left(\frac{4\pi d}{\lambda}\right)^2$$

(7)

Let $e$ denote BER, $Rs$ denote the symbol rate, and $N_0$ denote noise power density ratio. Using BPSK modulation for transmission, the required transmission power $P_t$ to achieve a certain receiver side BER $e$ can be expressed as follows [10]:

$$P_t = Rs \cdot b \cdot [erf^{-1}(2 \cdot e)]^2 \cdot N_0 \cdot A^{-1}$$

(8)

Let $\rho(i,j,\epsilon_{ij})$ denote the expected packet loss rate for sending packet $j$ from the source node to the relay node $i$ with expected channel BER $\epsilon_{ij}$, and $\rho'(i,j)$ denote the expected packet loss rate from relay node $i$ to the destination node. Then the overall transmission packet loss rate after relay can be expressed as

$$\rho_{ij} = 1 - (1 - \rho(i,j,\epsilon_{ij})) \cdot [1 - \rho'(i,j)]$$

(9)

According to Equations (6) and (7), we can find that the BER is related to the communication distance, transmission power, carrier wave length, and the symbol rate.

$$\epsilon_{ij} = \frac{1}{2} \erfc\left(\frac{P_t \cdot \lambda^2}{16\pi^2 \cdot d^2 \cdot Rs \cdot b \cdot N_0}\right)$$

(10)

Let $L_j$ denote the length of the sky camera image data packet $j$, then the data packet loss rate can be shown as:

$$\rho(i,j,\epsilon_{ij}) = 1 - (1 - \epsilon_{ij})^{L_j}$$

(11)

Let $\epsilon_{ij}'$ denote the BER of relay node $i$ to node $G$, then

$$\rho'(i,j) = 1 - (1 - \epsilon_{ij}')^{L_j}$$

(12)

According to Equations (8), (9), (10) and (11), we can get the end to end data packet loss rate:

$$\rho_{ij} = 1 - \frac{1}{2} \erfc\left(\frac{P_t \cdot \lambda^2}{16\pi^2 \cdot d^2 \cdot Rs \cdot b \cdot N_0}\right) L_j \cdot [1 - \epsilon_{ij}']^{L_j}$$

(13)

Let $P_t'$ denote the transmission power of the relay node, and $T_s$ denote the transmission time spent on delivering this packet. Then the energy consumption for transmitting data packet $j$ can be estimated as follows:

$$E_{asd} = \frac{(P_t + P_t') \times L_j}{T_s}$$

(14)

Let $D_r$ denote the distortion reduction of the data packet $j$, then the EHWSN/IoTs sky image transmission efficiency can be numerically evaluated as:

$$E_e = \frac{D_r \times (1 - \rho_{ij})}{E_{asd}}$$

(15)

In a real-world setting, each node should maintain its residue energy state, energy harvesting capability and its immediate neighbor relay nodes. The packet transmission energy efficiency, using different power and relay choices, will be estimated based on Equation (15). The best relay and power control choice will be acquired based on a simple search to transmit the current packet according to the energy efficiency and energy profiles.

The proposed algorithm pseudo-code is shown in Algorithm 1. This algorithm is to select the best relay node and optimal
transmission power for each sky-camera image data packet, the purpose of which is to achieve the highest image quality under stringent energy constraint. The algorithm description is as follows: First, estimate harvestable energy in the next period of time (e.g. 24 hours). Second, calculate the expected quality-energy efficiency for each transmission node under different power and relay node selection strategy. Finally, based on estimated harvestable energy, find the most valuable transmission strategy for each source data packet as the output of this algorithm. The output strategy includes whether a data packet will be sent, which node will be chosen as relay and how much transmission power will be used for sending this packet from source node to the relay node.

Algorithm 1: Joint relay selection and power control

1: Initialize Inputs/Outputs:
   Total relay node count N; energy harvesting power $P[N+1]$; node distance profile $d[N]$; relay node transmission power $RP[N]$; source node transmission power $SP_{max}$, $SP_{min}$; transmission power granularity steps $SP_{count}$; data packet number D; data packets distortion reduction measure $DR[D]$; data packets length $Len[D]$: minimum energy efficiency threshold $\epsilon$.

2: Estimate the harvested energy in the next 24 hours.
   $TotalEnergy[N+1] = \{0...0\}$
   For $i = 1$ to $N+1$
   For $j = 1$ to 24
   $TotalEnergy[i] = TotalEnergy[i] + P_s(h,t)$
   Endfor
   Endfor

3: Allocate efficiency array $DPE[N * SP_{count} * D] = \{0...0\}$
   For $i = 1$ to D
   For $j = 1$ to $N$
   For $k = 1$ to $SP_{count}$
   calculate energy efficiency based on Equation (15).
   Endfor
   Endfor
   Endfor

4: Sort $DPE$ from high to low. Get the sorted original index $SortedIndex[N * SP_{count} * D]$
   Allocate data packet register $DP [N] = \{0...0\}$
   Allocate data packet transmit strategy $DPTS[N,2] = \{0...0\}$
   For each index in $SortedIndex$ do
   $tmpDataIndex = get_DataPacketIndex( index )$
   If $(DP [tmpDataIndex] < \epsilon )$
   Continue
   Endif
   $tmpSrcPower = getSrcPower( index )$
   $tmpSrcCon = getSrcCon( tmpSrcPower, tmpDataIndex )$
   $tmpRlyIndex = getRlyIndex( index )$
   $tmpRlyCon = getRlyCon( tmpRlyIndex, tmpDataIndex )$
   Continue
   Endif
   $TotalEnergy[1] = tmpSrcCon$
   $TotalEnergy[1 + tmpRlyIndex] = tmpRlyCon$
   $DPR[tmpDataIndex] = TRUE$
   $DPTS[tmpDataIndex,1] = tmpSrcPower$
   $DPTS[tmpDataIndex,2] = tmpRlyIndex$
   Endfor

5: Output $DPTS$, done.

V. SIMULATION

In this section, we perform a simulation study and show the performance gain in energy efficiency and distortion reduction quality of the proposed approach. Transmission quality performance is evaluated in terms of summative distortion reduction of image data packets. The energy neutrality is considered as the constraint during all simulation scenarios. We use commercial platform Matlab to run the simulation program, and develop the lower layer error models in simulation source code. We built a one-many-one topology in simulation. This topology has one source node, five relay nodes and one destination node. The transmission power of source node can be flexibly changed as required. The position of each node is fixed. Sky image data packets are generated on the source node and relayed to the destination node. The destination node does data validation and discards incorrect data packets. The eventual sky image is reconstructed exclusively using data packets correctly received as the receiver. All nodes have energy harvesting components as power supplies.

The simulation settings are illustrated as follows: the transmission power is 0.28mW, the symbol rate is 100000Hz and the noise power density ratio is $4 \times 10^{-21}$. The optimization period is 24 hours. The energy harvesting profile is illustrated in Table II, which is based on the solar energy gathering statistical results in [20]. We started each optimization period at 9:00 am to simplify the energy harvesting-utilization issue, making sure there is harvested energy before packet transmission. According to Table II, the system starts with the solar energy charging state, and the battery is charged during this period. We also assume the wireless environment for transmission relatively stable.

Typical optimization problem parameters could include transmission power, transmission relay node, packet length, packet level retransmission, channel coding rate, and modulation scheme, etc. We select transmission power and relay node as optimization parameters because they are easy to adjust in a real-world setting, for example, the power level and next hop relay address can both be reprogrammed in TinyOS system for wireless sensor communications.

<table>
<thead>
<tr>
<th>T</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(mW)</td>
<td>50</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>58</td>
<td>54</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>T</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>P(mW)</td>
<td>25</td>
<td>40</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>T</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>P(mW)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

First we perform a communication distance study. Figure 2 shows the relationship between BER and node distance when transmission power is fixed. In this figure we can see the BER increased when we increased the distance. Based upon current power and channel loss settings, we found that when the distance is below 700 meters, the BER is close to 0, and when the distance is greater than 700 meters, the BER is abruptly increased. In general we can see, based on each channel and power setting we can find a “critical distance” to optimize the relay strategy, by performing appropriate transmission power and relay node selection. Figure 3 shows the relationship between the packet loss rate and communication distance. In this figure we showed the packet loss ratio of five different packet types with various lengths in JPEG2000 image code streams. Table III shows the distortion reduction and length of...
TABLE III

<table>
<thead>
<tr>
<th>DR</th>
<th>Length(bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>290515906.2</td>
</tr>
<tr>
<td>II</td>
<td>43366978.82</td>
</tr>
<tr>
<td>III</td>
<td>25885684.71</td>
</tr>
<tr>
<td>IV</td>
<td>11863336.7</td>
</tr>
<tr>
<td>V</td>
<td>3642474.551</td>
</tr>
</tbody>
</table>

these five types of packet.

![Fig. 2. BER with different distances](image1)

![Fig. 3. Packet Loss Rates with different distances](image2)

Fig. 2. BER with different distances

Fig. 3. Packet Loss Rates with different distances

According to above simulation results, when the distance of the two nodes is less than 500 meters, we can see there is rarely any packet loss. When the distance is between 500 meters to 700 meters, packet loss rates have abrupt changes from 0 to 1, i.e. from little packet loss to severe packet loss rates. When the distance is great than 700 meters, the increased BER leads to an extremely high packet loss rate close to 1. In such long distance communication scenarios, a relay node is necessary to help on decoding and forwarding the information packets.

We also perform transmission power and loss rate analysis. Assuming the average communication distance between nodes is 500 meters, we record the bit level and packet level error rates by dynamically changing the transmission power.

![Fig. 4. BER with different power](image3)

![Fig. 5. Packet Loss Rate with different power](image4)

Fig. 4. BER with different power

Fig. 5. Packet Loss Rate with different power

Figure 4 and Figure 5 show the BER and packet loss rate change when transmission module works in reduced power mode to save energy. According to Figure 4, when transmission power is greater than 60% of its full power, the BER could be extremely low and such low BER changes smoothly. According to Figure 5, because of the gradual change of BER, packet loss rate shows a gradual change as well. Thus, the transmission power control can flexibly fine tune the packet error rate when the communication distance is fixed. Since source sky camera data packets have different lengths, the packet loss rate for each packet shows variation when the same transmission power is applied.

We also investigate the transmission power control strategies for the slope areas, i.e. the power control will immediately impact the packet error rates. In the following simulation, the power of transmit module changes from 70% to 100% of the...
full power.

Our proposed approach is illustrated as “OurAlg” with joint power and relay control. For comparison, we used the Find the Nearest (FTN) algorithm in the controlled simulation. Unlike our proposed algorithm, the FTN algorithm always selects the nearest node as the relay node to achieve the lowest BER and packet loss rate.

Figure 6 shows the remaining energy in the source node. According to the result, there is no more energy in source node if it is run in the FTN algorithm. By changing the transmission power, our proposed algorithm successfully saves transmission power for the source node. Comparing the two algorithms, our proposed algorithm gives a higher transmit quality if there is at least a relay node in the network. The increase of the number of relay nodes can also enhance the remaining energy of relay nodes; however, it cannot lead to any improvement to the source node’s remaining energy. In FTN algorithm, the distortion reduction is limited by the source node’s energy; in our algorithm, the distortion reduction is restricted by relay nodes’ energy.

Figure 7 shows the remaining energy in a typical relay node. Compared with other relay nodes, this node has a little bit higher BER between itself and the sink node. In FTN algorithm, it wasn’t selected for relay because of two reasons. First, it provides a lower relay transmission quality, so it is in a low priority in FTN’s relay node selection. Secondly, FTN has a bottleneck of source node’s energy, so the source node usually runs out of energy before this node is selected as the relay. In our proposed algorithm, due to the source node energy management strategy and optimized relay node selection strategy, the source node is able to offload energy utilization to some relays.

Figure 8 shows the overall distortion reduction quality performance of the two algorithms. According to this figure, our algorithm gives a twelve percent improvement in the overall distortion reduction. The proposed algorithm achieved a higher performance for two reasons. The first reason is critical source transmission power management. If the system lost a relay node, it may lose some efficient pathways to forward data. If the system lost the source node, it will lose all the data. The source transmission power management of the proposed algorithm successfully reduces energy consumption of the source node. By improving the reliability of the critical source node, our algorithm enhanced the overall system level transmission ability. The other reason is optimized relay selection strategy. Our proposed algorithm selects a relay node considering the difference between data packets and overall BER. It allows the relay nodes energy to be used with a higher efficiency.

So far we have discussed the properties of our algorithm, when energy and data packet are limited. However, improvement in hardware and the framework of the smart grid may introduce unlimited power supply for certain nodes, and continuous incoming data packets due to large volume of traffic such as many sky camera images and advanced metering information. Here we also investigate these two scenarios in our simulation study.

Continuous incoming data packet supply often occurs in the smart grid system with intensive data gathering requirement. Figure 9 shows the distortion reduction of these two algorithms. Here we fund that the distortion reduction improvement of our algorithm can be up to 15%. In this simulation, we
The proposed scheme, the transmission power control and relay node selection strategies were jointly optimized based on multimedia packet distortion reduction and the energy harvesting profile of each node. Energy neutrality was also considered as an important constraint in the optimization problem. The simulation results showed that the joint control of power and relay selection strategy provided higher multimedia transmission quality in EHWSN/IoTs.

VI. CONCLUSION

In this paper, we proposed a new quality-optimized sky camera multimedia information gathering scheme for EHWSN/IoTs based smart grid solar power estimation. In the proposed scheme, the transmission power control and relay node selection strategies were jointly optimized based on multimedia packet distortion reduction and the energy harvesting profile of each node. Energy neutrality was also considered as an important constraint in the optimization problem. The simulation results showed that the joint control of power and relay selection strategy provided higher multimedia transmission quality in EHWSN/IoTs.

REFERENCES

Committee (TPC) member for many international conferences such as IEEE and the program chair of the ICST IWMMN 2010, and a Technical Program of IEEE CIT-MMC track 2012, the vice-chair of IEEE ICCT-NGN track 2011 ICST BodyNets 2013, the program vice chair of ACM RACS 2013, the chair and Data Dissemination in Vehicular Environments, the workshop co-chair of Networks Journal, the Guest Editor of three Special Issues for Hindawi IJDSN robotics. He won 2 Best Paper Awards of IEEE WCNC 2008 and ANSS.


Dr. Wei Wang [S’06, M’10] is an Assistant Professor with the department of Electrical Engineering and Computer Science, South Dakota State University, Brookings, SD, USA. He received his B.S. degree in Computer and Information Engineering from Xian Jiaotong University, China, 2002, and M.S. degree in Information and Communication Systems from Xian Jiaotong University, China, 2005. He received his Ph.D. degree in Computer Engineering from University of Nebraska - Lincoln, USA, 2009. His major research interests include wireless sensor networks, multimedia computing, information security, and educational robotics. He won 2 Best Paper Awards of IEEE WCNC 2008 and ANSS 2011. He serves as an Associate Editor of Wiley Security in Communication Networks Journal, the Guest Editor of three Special Issues for Hindawi IJDSN on Energy-Efficient Sensor Networks, Underwater Wireless Sensor Networks, and Data Dissemination in Vehicular Environments, the workshop co-chair of ICST BodyNets 2013, the program vice chair of ACM RACS 2013, the chair of IEEE CIT-MMC track 2012, the vice-chair of IEEE ICC-NGN track 2011 and the program chair of the ICST IWMNN 2010, and a Technical Program Committee (TPC) member for many international conferences such as IEEE GLOBECOM, ICC and WCNC.

Mahdi Farrokh Baroughi [S’03, M’07] was born in Tabriz, Iran. He received the B.S. degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran, in 1997, the M.S. degree in electrical engineering from Sharif University of Technology, Tehran, in 2000, and the Ph.D. degree from the University of Waterloo, Waterloo, ON, Canada, in 2006. He was an IC Design and Foundry Engineer with Emad Semiconductor Company, Tehran, from 2000 to 2002. Dr. Baroughi is an Associate Professor of Electrical Engineering at South Dakota State University. He is the author and coauthor of more than 60 journal and conference publications in the area of electronic materials and devices. His expertise and research interests are in the areas of electronic materials and devices with particular focus on photovoltaic, atomic and molecular layer deposition, enhanced light-nanomaterial interaction, advanced material and device modeling, and reliability in photovoltaics. Dr. Farrokh Baroughi is the Founder of the Photovoltaic Material and Device Characterization Laboratory and the Advanced Chemical Vapor Deposition Laboratory in South Dakota State University.

Dr. Honggang Wang [S’06, M’10, SM’13] is an assistant professor at UMass Dartmouth and is an affiliated faculty member of Advanced Telecommunications Engineering Laboratory at University of Nebraska-Lincoln. His research interests include wireless healthcare, Body Area Networks (BAN), cyber security, multimedia communications, cognitive radio networks, multimedia sensor networks, smart grid communications and Cyber-physical system. He has published more than 90 papers in his research areas, including more than 20 publications in prestigious IEEE journals. He also published papers in prestigious conferences such as INFOCOM, ICDCS, ICC, Globecom and ICME. He is the co-recipient of the Best Paper Award of the 2008 IEEE Wireless Communications and Networking Conference (WCNC). He serves as a Guest Editor for several journals such as IEEE Journal of Biomedical and Health Informatics (J-BHI) and IEEE sensors journal, an Associate Editor of Wiley’s Security and Communication Networks (SCN) Journal and KSII Transactions on Internet and Information Systems. He also serves as TPC Chair or Co-Chair of numerous conferences and workshops. He serves as a TPC Chair of 8th International Conference on Body Area Networks. He is the TPC member for IEEE INFOCOM 2013-2014, IEEE ICC 2011-2013, IEEE Globecom 2010-2013. He is a senior IEEE member and currently serves as a Board Co-Director of IEEE MMTC (Technical Committee on Multimedia Communications) Services and Publicity.

Yi Qian [M’09, SM’07] received a Ph.D. degree in electrical engineering from Clemson University. He is an associate professor in the Department of Computer and Electronics Engineering, University of Nebraska-Lincoln (UNL). Prior to joining UNL, he worked in the telecommunications industry, academia, and the government. Some of his previous professional positions include serving as a senior member of scientific staff and a technical advisor at Nortel Networks, a senior systems engineer and a technical advisor at several start-up companies, an assistant professor at University of Puerto Rico at Mayaguez, and a senior researcher at National Institute of Standards and Technology. His research interests include information assurance and network security, network design, network modeling, simulation and performance analysis for next generation wireless networks, wireless ad-hoc and sensor networks, vehicular networks, broadband satellite networks, optical networks, high-speed networks and the Internet. He has a successful track record to lead research teams and to publish research results in leading scientific journals and conferences. Several of his recent journal articles on wireless network design and wireless network security are among the most accessed papers in the IEEE Digital Library. Dr. Yi Qian is a member of ACM and a senior member of IEEE.

Dr. Wei Wang

Yi Qian

Dr. Honggang Wang

Mahdi Farrokh Baroughi

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication.