A novel *DTN* based energy neutral transfer scheme for energy harvested WSN Gateways

T.V Prabhakar
Centre For Electronics Design and Technology
Indian Institute Of Science, Bangalore
tvprabs@cedt.iisc.ernet.in

H.S Jamadagni
Centre For Electronics Design and Technology
Indian Institute Of Science, Bangalore
hsjam@cedt.iisc.ernet.in

Akshay Uttama Nambi
Centre For Electronics Design and Technology
Indian Institute Of Science, Bangalore
akshay@cedt.iisc.ernet.in

Krishna Swaroop
Centre For Electronics Design and Technology
Indian Institute Of Science, Bangalore
akrishna@cedt.iisc.ernet.in

R Venkatesha Prasad
Delft University of Technology
TUDelft, Netherlands
rvprasad@ieee.org

ABSTRACT

We propose and implement a self sustainable data transfer scheme for small and marginal farmers. In our scheme, farmers have to generate electricity to have access to technology. We conduct detailed power measurements with an 8 pole bicycle dynamo and show that it is indeed possible to drive GPRS technologies with this power. We propose Energy Transfer Budget, a metric for nodes to announce the energy available for accepting and relaying data. To achieve our goal, we exploit the DTN stack and introduce necessary modifications to its configuration. The results indicate that a 50 packet buffer has the least energy transfer budget and the latency of the data is about 31 seconds.

Keywords

ICTs, Agriculture, Bicycle dynamo, DTN, WSNs

1. INTRODUCTION - AGRICULTURE USE CASE

Small and marginal farmers own about 1 to 4 hectares of land and solely depend on rainfall for irrigation. Their lands are generally located at a higher elevation (2 to 25 meters) compared to the rich farm lands resulting in a high run-off. Farming in Semi-Arid regions is further characterized by low rainfall (500mm over 6 months). Crop production has been subjected to weather and large scale attack due to pest and diseases. Over 75% of the tillable land in Karnataka state, India, is dependant on rainfall. According to [1] the state has witnessed rainfall deficiency 1 out of every 4.3 years. In [2], the authors explore the application of wireless sensor network technologies for the benefit of small and marginal farmers. The idea is to provide information about the standing crop by evaluating its stress in adverse situations such as a drought, pest attacks and even low yield. The farmers could make informed decisions about investing in purchase of water to save the crop, or spraying a pesticide at the right time. Sometimes adding a nutrient during a specified period is an important advice to the farmer. The project site chosen was Chennakesavapura (Pavagada Taluk, Tumkur District of Karnataka, India). This heterogenous distribution has 10 sensors each in 2 clusters. The data collected by the sensor network include soil moisture, temperature, pressure, humidity and rain data. To relay the sensor data for the purpose of analysis, currently, the village has a telephone and GPRS communication technologies. The authors explored a Wi-Fi cum telephone network in cluster 1 and GPRS technologies in cluster 2.

Availability of grid power is a major concern across most villages in India. Often power cuts last from 12 to 16 hours a day and GPRS technologies require sufficiently high energy for their operation with about a peak current of about 1.6A can be observed during data transmission. In [3] discuss several issues related to power availability and its nexus to reliable data gathering in the field. The authors show that data transfer using GPRS technologies increases the reliability compared to other technologies due to reduced system components. The authors also show from measurements the high power requirements for GPRS and also the technology pitfalls in terms of packet retransmissions whenever there is an operator preference for GSM voice over GPRS packet data. While the authors do not solve the problem of power availability, they indeed show that packet buffering improves energy efficiency compared to packet by packet data transfer.

In this paper, our objective is to show that energy to power GPRS can easily be generated in the village; and by the villagers. We show that the system can be become free from grid power and work in a self sustaining mode. We propose and implement a scheme wherein an alternate source of energy; a power source such as an ordinary bicycle dynamo is sufficient to drive the GPRS system components. Our scheme utilizes a hybrid communication system comprising of Wi-Fi and GPRS technologies. Figure 1shows the big picture of solution we have implemented. The figure shows that data from the sensor sink node is transferred to the bicycle over a Wi-Fi connection and subsequently relayed to the data centre over a GPRS link. In this paper, we refer the bicycle system as the "Data mule" since it visits several clusters to download data from an aggregation point. The system on the bicycle runs out of harvested energy generated by the dynamo and stored in a supercapacitor.

For the purpose of data transfer from the field unit to the data mule, we utilize the Delay/Distruption Tolerant Network (DTN) stack from [15]. The DTN Architecture and and other key open issues are discussed by [8].These issues include connection disruption and heterogeneity. The architecture proposes a collection of protocol-specific convergence layer adapters to provide functionality and carry DTN protocol data units called "Bundles". In this stack, data is converted into user controlled bundles of data. Such bundles are then reliably transferred between two end points using the TCP protocol. Perhaps one important reason for the popularity of the DTN communication stack is its application in remote areas where communication infrastructure is nonexistent or difficult to establish. Several works in literature show novel ways to improve DTN stack performance. For example, in [9] the authors propose a system which implements a mechanism with the goal to minimize packet transfers between entities such as buffers and persistent storage and hence accelerate dtn transmissions. In [10], to solve the problem of message replication in DTNs, the authors propose an adaptive optimal buffer management scheme for a limited bandwidth and variable message size scenario. The authors use the assistance of global network statusus such as transmission opportunity, inter-meeting time and contact time. In [11], the authors port the DTN stack over a commerically available wireless Access Point. They show the impact of bundle size on throughput and goodput. Several works in literature also mention about data mules used for improving energy efficiency and efficient data gathering. For instance in [4] the authors analyze through a simulation, the performance of discovery and data transfer phases. In [5] the data mule is used to construct variable length shortcuts. The mules move between nodes that do not have direct wireless communication link adding a simultaneous delay increase and path length reduction component. In [6]the authors analyze the problem of optimal data transfer from sensors to data mules and derive an upper bound for the performance of ARQ-based data-transfer protocols. They propose an Adaptive Data Transfer technique that reduces significantly the time required by a sensor to transfer its messages. In [7] the authors propose "data mule scheduling" scheme to minimize data delivery latency. In summary, most existing works look at performance improvement but do not propose any application towards improvement of energy efficiency.

In our work, since agriculture sensor data does not have a strict real time constraint, we employ the DTN stack and exploit its features from the view of energy availability rather than connectivity. We propose an algorithm to towards

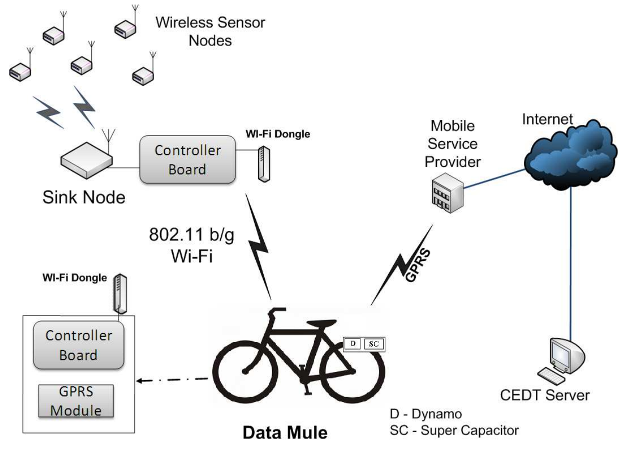

Figure 1: Proposed Scheme Showing data transfer over GPRS .

Table 1: Generated dynamo power with respect to cycle speed

Cycle speed in kmph	Power generated in watts
13.2	2.92
13.0	2.69
12.5	2.145
11.0	1.17

an energy based data transfer where data bundles are exchanged between DTN end points to match the minimum energy available between DTN node pairs without compromising the data reliability. Thus, the energy available is also converted into discrete bundles with a goal being energy neutral operation of the data mule carrying the GPRS relay.

2. EXPERIMENTAL SETUP

Since our primary source of energy for the data mule is the dynamo, it becomes important to characterize the source. Also, since we have done away with batteries, it becomes necessary to dimension the size of the supercapacitor for energy storage. The following subsections show the source characterization and supercapacitor value calculation.

2.1 Characterisation of the energy source

We used a 8 pole dynamo that is rated for a maximum of 3 watts and performed extensive measurements by rotating the dynamo at various speeds to verify the published maximum power capability. Table 1 provides a useful insight into the power generated at several cycling speeds. The results were obtained by conducting the Voltage-Current (V-I) characterization of the energy source. The results in table 1 indicate that it is possible to generate approximately 1.8watts to about 2.8watts for cycle speeds between 11 and 13 kmph.

2.2 Supercapacitor value calculation

Supercapacitors have started becoming popular due to their recent increased energy densities. Since our energy requirement is to the extent of retrieving the data bundles from the sink node and transferring the same over a GPRS link, we do not require an infinite buffer or even an oversized buffer. Based on the energy measurements we conducted (shown in the following section), we evaluated the capacitance required to transfer one data bundle of 50 packets. The minimum capacitance value required can be evaluated from equation (1)

$$C = \frac{2E}{V1^2 - V2^2} \tag{1}$$

Since the mama board works in the voltage range between 5.5volts (V1) and 4.35 (v2) volts,our calculations show that for transmitting a 50 packet buffer, a super capacitor of 75.14 Farads is required. For our experiments, we chose a 80 Farad capacitor. To calculate the time required for the cyclist to charge the capacitor, we used the equation (2). Our calculations show that 20 minutes of cycling at about 13 kmph is required to generate energy sufficient to transfer a 50 packet buffer.

$$t = \frac{CV}{I} \tag{2}$$

3. RESULTS

In this section we experimentally evaluate the most optimal size of the GPRS buffer. For this size, our new metric "Transfer Energy Budget" is found to be the least. In another measurement result, we evaluate the packet latency from the time a bundle arrives at the mule upto the time the data transfer to the end destination server is completed.

3.1 Energy Consumption by GPRS board

We have used a GPRS-Sensor Network bridge mama board from [12]. The board comprises of a GPRS module from Siemens (model - TC65) and a sensor network sink node. The sink is based on TI's [14] MSP 430 microcontroller and radio from XE 1205 radio from semtech [13]. For the purpose of this paper, sensors in the field were programmed to send a data packet to the sink node every 20 seconds. The packet size was fixed at 32 bytes. The sink node, upon receipt of the data packet, forwards it to the GPRS module's buffer memory. Memory for holding GPRS data is available both inside the module as well as on an external SD card format flash memory. We have used the internal free 1.7MB memory. The GPRS Module, depending on its state, can operate in 3 different modes i.e., Idle, Airplane, and Power Down. In Idle mode, the GPRS radio and other components of GPRS module will remain in "on" state all the time. In this mode, a TCP connection is established for every incoming packet and closed soon after. In Airplane mode, the radio alone can be turned on and off based on user commands. The module however, can continue to buffer packets and accept all commands. We have used this mode effectively to turn on the radio after buffering a certain number of packets. Soon after transmission of the buffered packets, the radio is pulled to "off" state. Finally, in power down mode, the entire GPRS module including the radio is turned down. A single command is required to turn on the system.

We conducted an experiment to evaluate the energy required for transmission of a single data packet over a GPRS link. We used packet buffering and adapted the store and forward paradigm on the GPRS module to save on the overhead of GPRS "on" state energy. The experiment was conducted by varying the buffer size and programming the GPRS module in Airplane mode. Once the buffer is full, the GPRS radio is switched to "on" state and a TCP connection is established between the GPRS TCP client and the TCP server located in the CEDT server.

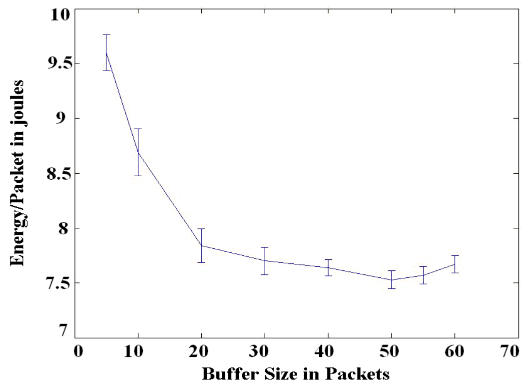

Figure 2: Plot of Energy per packet vs Buffer size for 95% confidence interval

Table 2: Energy/Packet for varying buffer sizes

Buffersize	TimeTaken to transmit in sec	Energy/Packet inJ
5	22.2	9.65
10	23.8	8.85
20	25.5	7.90
30	32.4	7.82
40	37.6	7.64
50	31.0	7.50
55	40.9	7.55
60	43.0	7.62

Figure 2 shows 95 % Confidence Interval Points with x-axis having different Buffer size and Y-axis having Energy/Packet to transmit. Energy/Packet is calculated using the equation 3 where V1 and V2 are initial and final voltage across the Super Capacitor.

$$E = \frac{C(V1^2 - V2^2)}{2} \tag{3}$$

As we increase the buffer size on the module, the transfer energy for a packet decreases until the buffer size is 50 packets. Soon, the energy increases; although slowly. By taking the 50 packet buffer, our results show that in order to complete a GPRS transfer for single packet, the minimum amount of energy consumed is 7.5 joules. Thus, for 50 packets, one would require 375 joules. This indeed is the "Transfer Energy Budget" we would require for successfully transferring data. We also evaluated the additional initial boot up energy required by the mama board to about 45 joules. This is the 60mA constant current drawn and shown in Figure 3.

Table 2 shows the energy required for transferring data for several buffer sizes from the GPRS module.

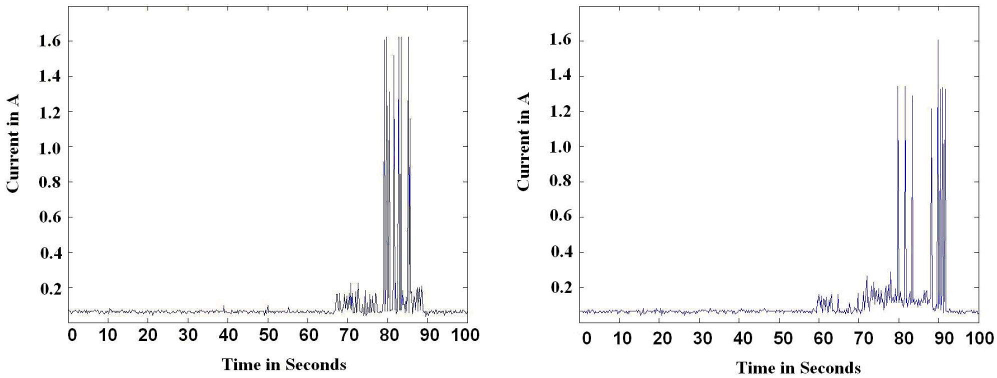

Figure 3: Variation in Current versus time for buffer size 5 and 50 respectively.

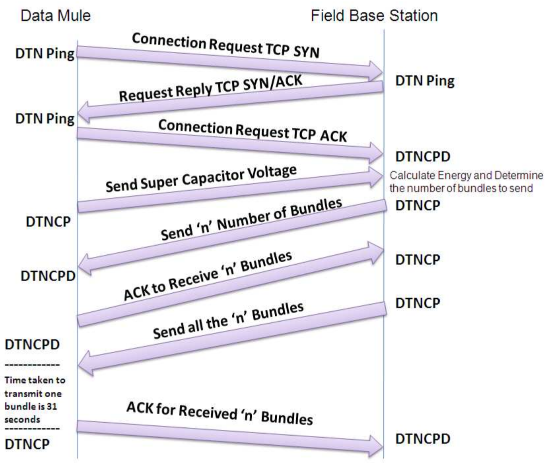

Figure 4: Ladder diagram for transfer of bundles based on the harvested energy

Figure 3 shows the variation of current with respect to time when the radio turns on with GPRS buffer size of 5 and 50 respectively. The two figures closely compare with the results tabulated and shown in table 2. For a buffer size of 5 packets, while the time for transfer is shorter, the spiky nature of the current together with the large weight of the overhead energy pushes the energy/packet to a significantly large number. We observe for the 50 packet buffer, the overhead is completely amortized over the transfer time. Thus, the energy/packet is the least. For the 60 packet buffer, the transfer time together with the current drawn by the system is significantly longer and thus increases the energy per packet.

3.2 DTN Bundle Transfer Based on Harvested Energy

The sensor sink gathers all the packets from the field deployed sensors over a serial link and passes them to the controller board towards data bundling operation. The controller board is based on Intel's Atom processor and boots Ubuntu operating system from a USB pen drive. The controller board also has a Wi-Fi dongle over USB and primarily used as the DTN interface. From the previous section, since we know that a 50 packet buffer meets the required transfer energy budget, we bundle the incoming sensor data into 50 packet bundles.
The data mule comprises of a controller (also based on Intel's Atom Processor) to interface the Wi-Fi dongle and also for the purpose of interfacing to the GPRS module attached to the mama board. The mama board alone runs on harvested energy from the dynamo.

The Ladder Diagram in 4shows the implementation of energy negotiation and data bundle transfer between the field station node and the data mule. Soon after the connection is established, the data mule uses the "DTNCP" command and sends the supercapacitor voltage. The field station unit calculates the energy available using equation (3). The datamule upon receiving the data bundles, forwards the data into the GPRS module's buffer. We estimated the time for a 50 packet bundle as 31 seconds on the data mule from the time the bundle arrives from the field station until the data is transferred successfully over the GPRS. Algorithm 1 completely captures the DTN stack working.

4. DISCUSSIONS

Due to hop nature of the data, we realize that the system requires a sufficient level of data reliability. Two TCP connections are required for data transfer from the sensor sink node to the end server. The DTN stack upto the GPRS system utilizes and relies heavily upon TCP to ensure that the bundles are transferred and then placed in the GPRS buffer. The second TCP connection runs between the GPRS node and the end server. Here again, data is quite reliable due to TCP as the transport. Also, the lower layers of GPRS support Automatic Repeat Request (ARQ) to further increase the reliability. We have introduced the energy based data transfer and ensured that data under any circumstance is not removed until it reaches the end server. Thus, DTN from the energy perspective is a novelty in our proposed scheme. Our scheme also ensures that there are no replaceable components such as batteries. An ideal supercapacitor has infinite charge-discharge cycles and it also does not require any complex circuitry for charging.

Currently, in our algorithm, DTN entities use the voltage

Algorithm 1 DTN Algorithm for Energy based bundle transfer

1: The field station node and the Data Mule establish a connection over Wi-Fi.
2: The Data mule sends the voltage across the super capacitor charged using the dynamo.
3: The field station calculates the available energy using equation (3) and determines the number of bundles to be sent to the data mule. The assumption here is that the sink knows the size of the energy buffer. In other words, the capacitance is known.
4: If the Energy available is less than the minimum Energy required i.e. 420 J, then no bundles are sent by the field station.
5: After sending the bundles to the data mule, the field station node awaits an acknowledgement (ACK).
6: The data mule after receiving a bundle does not send ACK to field station; instead it transfers the bundle into the GPRS buffer for transmission to the remote server over GPRS.
7: Once the buffer is sent successfully over the GPRS, the Data mule sends an ACK to field station node.
8: Then the field station node deletes all the transferred bundles.
9: If the data mule has more energy, at least 420 J, the mule requests for more bundles and the algorithm repeats from steps 1 to 9.

across the super capacitor for the energy based transfer. Also, to keep the system simple, a one way energy availability approach was chosen. In practice, it is also possible that the energy of the field station unit is the limiting factor. The proposed Transfer Energy Budget is easily amenable for bi-directional usage to transfer data and transform the model to be a generic one.

5. TOWARDS A SUSTAINABLE MODEL

The model we have proposed becomes sustainable due to the following two reasons: (a) The farmer has to generate energy to take advantage of modern technologies and access to expert advice. The success of his crop yield is directly dependant on his own efforts. We think that apart from tilling the land and watering the crop, he has to additionally generate energy for crop information and thus evolve a financially sustainable model (b) A second reason for sustenance comes from the system we have built. There are no replaceable components such as batteries and associated charging electronics. There is no dependency on grid power and thus operating costs are kept to the bare minimum.

6. REFERENCES

[1] Vijay Kalavakonda and Olivier Mahulb, *Crop Insurance in Karnataka*

[2] J. Panchard, S. Rao, T.V. Prabhakar,H.S. Jamadagni,J.P. Hubaux. COMMON-Sense Net: Improved Water Management for Resource-Poor Farmers via Sensor Networks. *In: International Conference on Information and Communication Technologies and Development, 2006.*, ICTD 2006, May 2006.

[3] T.V. Prabhakar,H.S. Jamadagni,Amar Sahu, R. Venkatesha Prasad. Lessons from the Sparse Sensor Network Deployment in Rural India. *In: 11th International Conference ICDCN, 2010.*, ICDCN 2010, Jan 2010.

[4] G. Anastasi, M. Conti, M. Di Francesco. Data collection in sensor networks with data mules : An integratedd simulation analysis. *In: Computer and Communications IEEE Symposium, 2008.*, ISCC 2008.

[5] Chang-Jie Jiang, Chien Chen, Je-wei chang, Rong-Hong Jan, Tsun Chieh chiang Construct Small World's in Wireless networks using data mules. *In: IEEE conference on Sensor networks ubiquitous and thrustworty computing, 2008.*, SUTC 2008.

[6] G. Anastasi, M. Conti, Emmanuele Monaldi, Andrea Passarella An Adaptive Data-transfer protocol for sensor networks with data mules. *In: IEEE conference on World f wireless,Mobile and Multimedia Application, 2007.*, Wowmom 2007.

[7] Ryo Sugihara, Rajesh K Gupta Optimizing Energy-Latency Trade-Off in Sensor Networks with Controlled Mobility. *In: IEEE conference on INFOCOM,2009.*, INFOCOM 2009.

[8] Kevin Fall, Stephen Farrell DTN : An Architectural Retrospective. *In: IEEE Journal on selected areas in Communications,2008.*, VOL 26, No 5, June 2008.

[9] S Dimitriou ,V Tsaoussidis. Effective Buffer and Storage Management in DTN nodes. *In: Ultra modern Telecommunications and workshops,2009.*, ICUMT 2009.

[10] Young Li, Meng Jiong Qian, Depeng Jin, Li Su, Lie Guang Zeng. Adaptive Optimal buffer Management policies for Realistic DTN. *In: IEEE proceedings GlobeCom ,2009.*, GLOBECOM 2009.

[11] F Gil-Castineira, F.J Gonzalez-Castano, R. Asorey -Cacheda, L. Framck and S. Paillard Practical development of an Embedded Hybrid Wireless DTN node. *In: Satellite and Space Communications, 2006 International Workshop.*, Sept 2006.

[12] Shockfish *http://www.tinynode.com.*

[13] XE1205 TrueRF *http://www.semtech.com/xe1205.*

[14] MSP 430 *http://www.ti.com/msp430.*

[15] Delay Tolerant Networking Research Group *http://www.dtnrg.org/wiki.*