Localized data gathering paradigms for small and marginal farm lands in Semi-Arid regions - Issues and Concerns

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***Abstract*—In this work we explore the application of wireless sensor technologies for the benefit of small and marginal farmers in semi-arid regions. The focus in this paper is to discuss the merits and demerits of data gathering & relay paradigms that collect localized data over a wide area. The data gathered includes soil moisture, temperature, pressure, rain data and humidity. The challenge to technology intervention comes mainly due to two reasons: (a) Farmers in general are interested in crop yield specific to their piece of land. This is because soil texture can vary rapidly over small regions. (b) Due to a high run-off, the soil moisture retention can vary from region to region depending on the topology of the farm. Both these reasons alter the needs drastically. Additionally, small and marginal farms can be sandwiched between rich farm lands. The village has very little access to grid power. Power cuts can extend up to 12 hours in a day and upto 3 or 4 days during some months in the year. In this paper, we discuss 3 technology paradigms for data relaying. These include Wi-Fi (Wireless Fidelity), GPRS (General Packet Radio Service) and DTN (Delay and Disruption Tolerant Network) technologies. We detail the merits and demerits of each of these solutions and provide our final recommendations. The project site is a village called Chennakesavapura in the state of Karnataka, India.**

***Index Terms*—Energy efficiency, Bicycle dynamo, DTN, GPRS, Sparse sensor networks.**

I. Introduction - The need for localized data gathering

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. The Indian Government had long introduced crop insurance to farmers to pass their weather related risks to a third party. Farmers from the state of Karnataka participated in almost all risk management schemes offered by the Government. The first ever crop insurance was introduced in the year 1972, was based on "Individual farm" approach for cotton. It also included groundnut, wheat and potato. Soon the The pilot crop insurance scheme (PCIS) was launched in 1979. This was based on"area yield" approach. In the year 1985, PCIS was replaced with another scheme called the Comprehensive Crop Insurance Scheme(CCIS). The National Agricultural Insurance Scheme (NAIS) launched in 1999 replaced the CCIS, and Karnataka started adapting it from the year 2000 onwards. Most schemes were unsuccessful and had to be discontinued due to administrative and financial difficulties. All the insurance programs have generated claims well in excess of premiums. For example, for CCIS, only 4 out of 22 states had insurance charges greater than the claims. Also, for a period of 12 years ($1985 to 1997$), one single crop, namely, groundnut received 48.8% of insurance claim from the state of Gujarat.

A weather-index based insurance contract is a possibility since there exists a high correlation between crop yield and rainfall parameters. However, small and marginal farms are non-contiguous. Usually natural features like large reserved areas, fallow patches, dried up ponds and uneven earth mounds separate them. Also, they might be sandwiched between rich farm lands who have substantial land holdings. Two important and characteristic features of these lands is the high run-off and high variability in soil texture. One may notice a change in the terrain and soil texture over 100 meters. . The farmer may have had an extremely low crop yield despite a good rainfall in his village. Therefore, a high rainfall indication might not necessarily reflect a high soil moisture content.

The uncertainty of claims for insured farm lands based on the area-yield approach is not completely suitable for an individual farmer. This leads us to data monitoring individual farm lands and aggregating to a central system. There is need for a mechanism to collect localized data over a wide area. Insurance companies can now look up rainfall and soil moisture parameters specific to individual farm lands to cover the risk. Another reason for requirement of localized data is towards individual advice on crop status. Predicting crop yield from software based crop model simulations is another well researched area. Input parameters such as water stress, soil moisture and other input parameters are used predict the yield. Timely advice from models can let farmers adapt their farming strategies. A wireless sensor network (WSN) deployed to monitor environment parameters of small and isolated farms but spread over a wide area has to be *sparsely* deployed.

In this paper, we study a few individual farm based localized data gathering and relay paradigms. Our experiments were continued in the site mentioned in [3], where the authors explore the application of wireless sensor network technologies for the benefit of such farmers in semi-arid regions. 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, spraying a pesticide at the right time, or adding a nutrient during a specified period. The project site chosen was Chennakesavapura (Pavagada Taluk, Tumkur District of Karnataka, India). This heterogenous distribution has 10 sensors each in 2 clusters. The *sparse* network was necessitated due to several considerations. Apart from the main motivation being towards crop insurance and individual advices, there are other important reasons as well. Firstly, the cost of sensors still continue to be around the \$100 US dollar mark [6] which make them expensive for a fully connected dense network. Secondly, in our project it was essential to have a cost-effective connectivity while reducing power required at sensors. To relay data from villages, we explored telephone network in cluster 1 and GPRS technologies in cluster 2 due to its increased penetration in rural areas.

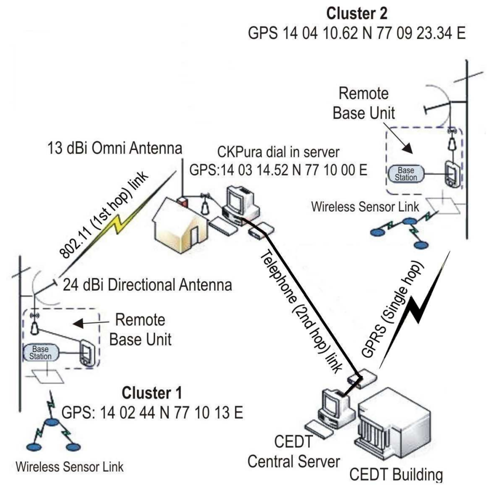

Fig. 1. Existing Deployment

II. Issues in reliable data gathering

Figure 1 shows the network deployed at CKpura. We initially setup cluster 1. It uses Wi-Fi with a telephone dial-in system to relay the data to the data centres. The gathered data requires 2 hops to reach CEDT building data centre. Subsequently, we later explored the possibility of using GPRS technologies in cluster 2 to relay data and requires 1 hop to reach the CEDT building data centre. We will discuss the data reliability issues with both the clusters.

A. Issues with cluster 1

Soon after deployment, the sensor network suffered from outages due to multiple problems. We broadly classify them as: (1) outage due to sensor node's flash memory corruption. Flash memories in outdoor environment under ambient temperature exceeding $35\deg$ and under low battery voltage were found to corrupt the software. We also found that a strong correlation exists between a lightning strike and flash memory corruption. Battery replacements have to be done periodically to ensure that sensors continue to sense and communicate. The detailed report of this problem can be found in [4]. (2) outage due to unreliable data communication between nodes. Our deployments were allowed by the farmer just a few days before the sowing season. Soon after a few weeks, due to sprouting, it was found that the ground conditions alter the RF characteristics of the radio, thus affecting the link connectivity between sensor nodes. This is particularly true in our *sparse* deployment, where the inter node distance is over 50 to 75 meters. (3) Outage due to node vandalism and thefts. About 30% of the deployed nodes were lost or damaged due to theft and vandalism. (4) outage of long distance connection. The telephone dial-up connection is running for over 2 years now. In these years, there were several instances when the telephone link & exchange were unavailable due to outages. These outages were caused due to: (a) heavy rains (b) equipment failures (c) complete discharge of large battery backups due to unavailability of grid power. The village side dial-up modems were damaged by lightening strikes 5 times till date and thus preventing connectivity to from urban data centres. Also, very often the rural aggregation server is unavailable either due to lack of grid power, or due to fluctuation in input voltage. The voltage varies from about 90 volts to about 400 volts, causing a trip in Uninterrupted Power Supply(UPS) systems. This voltage fluctuation also affected the field aggregation units where the battery chargers get charred due to a high voltage spike. There were 10 units destroyed in these years.

Table I summarizes a few important problems we faced in cluster 1. The network outage statistics was collected for 1 year. The last column shows the number of man hours spent in restoring the network. In summer, the soil compaction reduces drastically due to lack of moisture in the soil and thus create an air gap between the sensor and the soil. This often lead to the sensor reading illegal soil moisture values. Since our technology intervention was in the peanut growing region of CKpura, we placed the soil moisture sensors in depths of 30 and 60 cms depth. Other network outages include RF cable and connector problems, loss in line of sight due to foliage and lightning. There were outage problems in the field station dial-in server unit and in the field at the remote base unit side due to lack of grid power.

Wi-Fi connectivity has its own set of problems. One of the major problems in the village concerns the availability of grid power. In view of this, some of the drawbacks of the Wi-Fi based design become apparent.

a) *Wi-Fi link failure:* Our *sparse* network has a range of 1 to 2.5 kilometer Wi-Fi connection between the remote base unit and the dial-in server placed in the field station. Such a distance would require line of sight. Signal fading and trees with thick vegetative growth have hindered a reliable connection.

b) *Power Cuts:* Due to frequent power cuts, although the Wi-Fi access point is powered with a large battery, and the dial-in server with a UPS system, often, due to low battery charge either systems switch off. In the event of unavailability of the dial-in server, to minimize data loss arriving from the remote base unit, we placed a single board computer to store the data locally on a pendrive.

c) *System is not self operational:* Related closely to the previous point, with the current setup, if the village does not have power for 2 to 3 days, manual intervention is required to collect the data from the pendrive. User intervention is also needed to establish a dial up connection between the dial-in server and the CEDT building data centre.

d) *Complex System:* The Wi-Fi bridge design includes many components which makes the system complex and unreliable. For instance, the power output connection from the access point to a external antenna requires a type "N" RF connector and associated pigtail termination. Since these provide limited operations and also contribute in signal attenuation the system with Wi-Fi is complex and unreliable.

B. Issues with Cluster2 - GPRS

Cluster 2 was deployed at a different location. A spot on the top of the local school in the village was identified for location of the remote base unit. We verified data logging at the aggregation unit. We made several unsuccessful attempts to check if Wi-Fi link connectivity was possible to the dial-in server field station. Our GPS measurements indicated that the ground was elevated compared to the field station with dense trees in the middle. For a few days we managed with off-line data transfer, where we used a pen drive to copy data from the remote unit to the dial-in server at the field station.

Having identified the problems associated with Wi-Fi bridges for relaying data from rural aggregation points to urban data centres, we started to explore the possibility of using GPRS technologies. Meanwhile one of the Mobile phone service providers has put up hardware and high towers that are accessible in this region. Hence the aggregation unit's hardware was extended by the addition of a GSM/GPRS module.

In view of the GPRS setup, one can now do away with the field station dial-in server and its downtime related issues. One may also avoid the telephone dial-in connection and the unreliability due to RF connectors. All the data can be directly delivered to any location by the cellular operator. We interfaced a "GPRS - Sensor Network" bridge mamaboard from a company called shockfish. The board has the required electronics to function both as base station sink node and also provides GPRS connectivity. The Seimens TC65 GPRS module mounted on the mamaboard has sufficient flash memory

TABLE I
PROBLEMS RELATED TO DEPLOYMENT - CLUSTER1

Problems Faced	Reason	Number of times	Troubleshooting	Effort (Man Hours)
Mote sensing negative value	Probe loosing contact with the soil especially during summer	8	Ensure that the probe is in contact with the soil. Resetting the mote has also helped a couple of times	1.5 hours each time
No Packet Transmission	Low Battery Voltage, Mote connectivity problem, RF cable end-to-end connectivity problem, Loss of LOS due to foliage	20	Replace Battery, soldering wires when snapped, cleanup the dust on the RF terminals. Sometimes replacing the RF cable was the only solution, align the antenna	1 to 2 hours each time
Flash corruption due to lightening	Sometimes because of heavy lightening the mote's flash got corrupted	5	Reprogram the node. Lightening conductors have also been erected on the poles.	0.5 hours
Problems at the BaseStation unit	(I)Low voltage on the back up battery due to unavailability of grid power especially when there is no power for 3 days and over thereby bringing down the network. (II)High voltage spike damaging the battery charger	(I)Recurring, (II)8	(I)Replace the backup battery with charged battery, (II) Replace charger with another charger	(I)2 to 3 hours, (II) 2 hours
Problems in the Field station unit	(I)Low voltage on the back up battery due to unavailability of grid power especially when there is no power for more than 2 days thereby bringing down the system and related components (II)High voltage spike damaging the telephone modem	(I)Recurring problem, (II)8	(I)Used a battery with larger capacity that gives a backup of about 8 hours, (II)Replace modem with a new modem	(I)turn off CRT monitor, modem etc when there is low power, (II)1 week

for data buffering and supports several power saving modes of operation. For instance, in *Airplane* mode, the current drawn by the mamaboard was 10mA every 5 milliseconds(ms). This mode enables shutting down only the GPRS radio. We also measured the current consumption of the mamaBoard when the TC65 module is running in *Idle* mode. This mode enables the module but disallows GPRS data transmission and typically used for accessing internal flash memory. This mode draws a maximum of 200 mA every second.

GPRS technologies require sufficiently high energy for their operation. Energy efficiency and battery backup lifetime can be extended if we minimize the transmission energy overhead and avoid GPRS transmission for a single packet. Several buffering techniques were explored. Figure 2 shows the current drawn during the transmission of 10 data packets over GPRS. While the initial part corresponds to the module turning "on", a peak current of 2A is observed during the packet data transmission. From 2 we evaluated the ampere-hour(AH) requirement for packet transmission for one day to be 0.7AH/Day. By installing a 12V and 24AH battery in the field, such a system should provide a life time of about 34 days from full charge until cutoff. However, our practical observations showed that the battery would not last 4

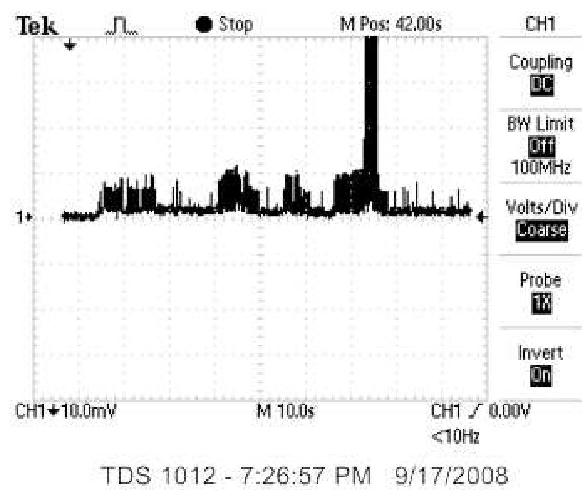

Fig. 2. GPRS Transmission of 10 data packets

days. Our investigations revealed lack of grid power to charge the system was draining the battery. The battery was never able to go to full charge. There was also the issue of self-discharge. Often low voltage that persisted in the village did not allow the chargers to work. The battery charger was shutting down due to extremely low voltage (around 90 – 120 VAC). We even specially

Fig. 3. Chamber Construction

ordered chargers to work under low voltages.

C. Issues in Node protection and packaging

We had node vandalism and thefts. The RF cables that were used for connections have a scrap resale value and were ripped off from the ground. Some of the radios PCBs were stolen. Since field deployments need to sustain very harsh conditions both for the signal and sensor, several deployment prototypes and packaging alternatives were attempted. For instance, we found that by burying the IP65 sealed packaged sensor box in the soil, the communication range was about 30 meters. In another scenario, we placed the sensor box on the ground and obtained a maximum range of about 90 meters. This was a near line of sight at ground level. However, thick vegetation would soon remove this benefit. Further, since both the schemes, apart from a limited range were not tamper proof, we finalized at placing the sensor box within a 30cm manhole chamber with a locked cover. The transmitter's simple antenna was extended by a coaxial cable to an external dipole mounted at a convenient height of about 4m from the ground. Silicone sealant was used for ensuring all openings for wires. The whole setup was covered with topsoil to prevent unnecessary visibility. Figure 3 shows a picture of this alternative. Although this alterative successfully prevented thefts, after some rains during the good monsoon, the chambers were found to be flooded and discharging the batteries. the sensor electronics was faulty. Some of the PCBs could be recovered and used, while the others were damaged. The chamber locks rust quickly and the mechanisms prevent easy opening.

III. Some worked out solutions

In this section we propose a few solutions to the problems encountered throughout the deployment period. While some of the pieces are work in progress, others have been tried out successfully.

A. Data relay - A case for energy generation

Our data gathered using the sensor network can tolerate substantial delay of over several hours before it reaches the data centre. Thus optimizing the model for delay is not a requirement. The system can also tolerate packet loss. For instance, if one temperature sample collected every 15 minutes is lost, such a packet loss is trivial for our analysis. Thus the model does not have to be optimized for packet loss as well. One of the major problems both in cluster 1 and 2 concerns the unavailability of the grid power in the village. The Wi-Fi system is mature and simple to use. It offers connectivity over 200 meters of line of sight (LOS). The GPRS is a power hungry technology but has the advantage of relaying data directly to data centres.

We are motivated to free the data relay system from the power grid. One obvious choice is to generate power from solar panels to power the GPRS relay system at each cluster. However, this would mean that we once again fall back on batteries, solar chargers, maximum power point tracking circuits and last but not the least - a good sunlight. Such as system besides attracting attention, requires replication at each cluster, bringing down the reliability of the complete network. In this paper, our solution comes from the observation of table I where there is a high level of manual intervention to restore a network outage. We propose human on a bicycle to assist power generation to support data relay. In this solution, we are considering a hybrid network technology comprising of a "Wi-Fi - GPRS" bridging system. The overall idea is to opportunistically download the data using a Wi-Fi - GPRS enabled device, fitted to a bicycle. The data is then bridged across to GPRS interface and relayed to the data centre. The complete system is expected to run on power generated by a bicycle dynamo. The energy is generated when the cyclist moves from one cluster to the other. We propose a low power device such as a PDA or a similar device, which integrates both the technologies to complete the bridging functionality. We have done away with batteries; instead store the generated energy in a low leakage super capacitor. Since super capacitors have higher power densities compared to available batteries, they will be able to source the peak power requirements of the GPRS system. Since

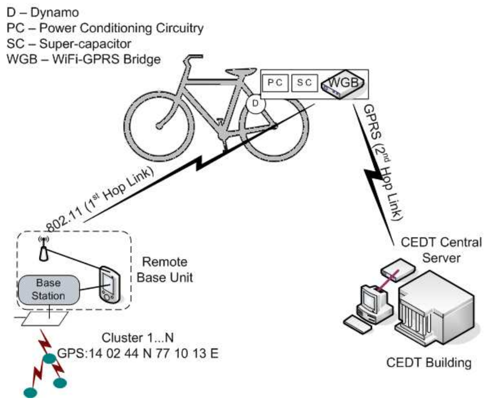

Fig. 4. Proposed Deployment

the marginal farmlands are non-contiguous, our bicycle model of a data relay is ideally suited. It has to travel from one set of marginal farm lands to another set.

Bicycle dynamos have long been known to give a power of 3watts.,i.e they source about 500mA at 6 volts at about 10 to 20km/hr speed. From figure 2, we can observe that a 2 minute cycle ride should be sufficient to complete a GPRS transmission of 10 packet upload to the data centre. A few additional minutes of cycle ride would be required to source energy for the Wi-Fi based data download from the remote base unit. Thus a simple bicycle ride with a dynamo from one cluster to another should take care of the energy requirements to relay data from the village to the data centres.

Figure 4 shows our proposed data relay system. Data from farmlands arrive at the aggregation remote base unit. A cyclist visits each of these clusters, typically two times a day. Each time, data gets uploaded to the data centre using GPRS technologies. The figure also shows the cycle dynamo, power conditioning unit and a suitably sized super capacitor. The cycle as carries the Wi-fi - GPRS bridge device similar to a PDA.

For our PDA needs, we are currently working on use of low power system of module (SOMs) to build our bridging system. One bridge would be required to at the remote base unit to collect and store the data arriving at the sensor base station. We have ported linux operating system and built our system using GumStix's Overo OMAP 3503 Application Processor with ARM Cortex-A8 CPU along with a summit expansion board for USB peripheral support. We are considering porting and evaluating the Delay Tolerant Network (DTN) [5] stack and provide DTN node capabilities. The second bridge would be required for the dynamo powered Wi-Fi - GPRS bridge with a DTN node capability as well.

Fig. 5. New Packaging Box

We think that DTN offers us data reliability and also best suited for systems running out of harvested or generated power. To ensure high reliability, data is packaged into bundles before transporting over the link.

B. node protection and packaging

Concerning the node protection and packaging, an alternative which is currently working well is a protected box with locking facility mounted on the antenna pole at about 1 foot above the ground level. Figure 5 shows this setup. This box prevents water logging and dust proof to some extent. The box is mounted to the antenna pole in such a way that removing the box requires considerable effort. This arrangement has the advantage of easy maintenance and quick replacement of batteries. All the necessary mechanical hardware was fabricated locally by mechanics.

C. Sensor network reliability

To ensure that the sensor network gathers data reliably, we conducted extensive range measurements. A wireless packet sniffer test platform was used for placing and testing the inter node connectivity. Also, to avoid flash corruption due to lightning, we installed lightning conductors at about less than half meter above the sensor antenna and found that the flash corruptions due to lightening strikes came down drastically. We also optimized on system energy by adjusting the duty cycle and also ported energy efficient media access with low power listen (LPL) mechanisms and routing protocols which reduce beacon messages. The microcontroller and radio sleep states were fully exploited.

IV. Related work

Sensors monitoring small and marginal farm lands have to be deployed in a manner not to obstruct routine agricultural operations and yet participate in the network formation. Most literature about *sparse* networks mention about mobile entities such as "Mule" visiting the field to periodically collect data and thus obviating the need for a fixed network infrastructure. None of them point out the reliability of data collection and lack of grid power in the village. In [7] a three tier architecture is presented and analyzed for collecting data from the field. Although no implementation is proposed, the paper proposes performance metrics such as Latency, Sensor power, data success rate, and infrastructure cost. In [8] the issue of energy efficient data collection in *sparse* networks is addressed. It proposes a protocol called "ADT" and conducts a detailed analysis. In [9] simulation results are presented indicating that controlled mobility is effective in prolonging network life time while containing the packet end-to-end delay, which is usually high in situation where the mobility is uncontrolled. Myths in rural connectivity is discussed in [10] where the focus is on applying Wi-Fi based broadband technologies for cost-effective rural communication. The paper discusses only about E-Mail and Voice mail services offered to residents in rural villages. The model uses village kiosks and a mobile access point mounted on a tree visiting one village after the other. While our bicycle is indeed a data mule, it generates electrical energy by running on small pathways deep inside farmlands to collect and relay the data.

V. Summary and Conclusions

In this paper, we discussed the merits and demerits of 3 localized data gathering and relay paradigms. Mature technologies such as Wi-Fi and GPRS technologies are suitable if exploited appropriately. They can be put to work to one's advantage, even in harsh conditions, where availability of grid power is intermittent. Relaying to data centres is not anymore dependant on availability of grid power, but dependant on human beings arriving on a bicycle at an aggregating point. A dynamo fitted to the bicycle stores the generated energy in a super capacitor of a suitable size. We had done away with batteries. Thus there is no need for battery chargers and power requirement to charge the batteries. We get the additional benefit of infinite charge and discharge cycles. With the cycle dynamo system, we need to only generate energy to match functions related to acquiring data from the remote base unit and relaying the same to data centres using GPRS. Thus an energy matched operation is sufficient. We do not require a large storage or any other energy efficient mechanisms to manage residual energy at the super capacitor.

VI. Future work

Our immediate task is to complete the system design of the bicycle dynamo based data acquisition and relay system. The DTN technology was proposed for occasionally-connected networks suffering from frequent partition. We want to study the DTN stack's response to power availability as a parameter.

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VII. About the authors

The authors of this paper have been working on ICT for development a little over one decade. The authors work in areas related to Communication Networks, Electronics Product Design and Fine mechanics. The department offers a very successful post graduate course on electronics design, with emphasis on hardware and system building components. The department has strong research in power electronics, vlsi and communication networks.

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