The Development of a Dynamic and Robust Event-Based Routing Protocol in Wireless Sensor Networks for Environmental Monitoring

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Abstract—**Wireless Sensor Network (WSN) technology promises to allow users to monitor fine-grained, dynamic changes in an outdoor landscape. Such systems can be used to improve the local environment but there are significant problems to be overcome in translating this vision into working systems. This paper outlines the challenges and describes the issues involved in the design of a reactive and robust, event-driven routing protocol for environmental monitoring of soil moisture: when the rain falls and soil moisture is changing rapidly, measurements are collected frequently, whereas during dry periods between rainfall events, measurements are collected much less often. Hence any proposed solution must be reactive yet robust in these wireless environments.**

This paper outlines the challenges in supporting such an environment and demonstrates a solution approach based on the modification of a well known reactive routing protocol, AODV, as well as different routing algorithms that are able to adapt to changes in part or all of the sensor network. Proposals to build a testbed to evaluate the proposed solutions are outlined.

Index Terms—**Wireless Sensor Networks, Reactivity, Reliability, Soil Moisture**

I. INTRODUCTION

The rapid evolution of wireless technologies and the significant growth of wireless network services have made wireless communications a ubiquitous means for transporting information across many different domains. Within the framework of Wireless Sensor Networks (WSNs) [1], there are many potential situations where a WSN can be deployed to support numerous applications. However, current real-life applications of WSNs are very limited. The main reason for the delay in the development of new services is the lack of a complete set of standard mechanisms which can be used to build different application environments [2].

Environmental monitoring is a natural candidate for applying sensor networks [3], since the variables to be monitored (e.g., temperature and soil moisture) are usually distributed over a large spatial region. For example, because the sun in the Middle East is present for at least 12 hours per day and hence the environment is quite dry, soil moisture needs to be regularly and accurately measured to allow targeted irrigation techniques to be implemented. This means that wireless sensor networks could be widely deployed to detect when and where it is raining and hence when certain measures could be applied [4].

In order to achieve this using Wireless Sensor Networks, certain challenges need to be addressed. Firstly, we need the system to react correctly to specific events: in this case the presence of rain. However, this can be over all or the part of the region being monitored. Secondly, once the event is detected, the affected nodes need to sample the environment at a much faster rate (i.e. from sampling every ten minutes, say, when it is not raining to sampling every few seconds when it is raining). This means that much more bandwidth should be made available to these rain-affected nodes. Hence resources and routing mechanisms must react in this situation to ensure that the required information is quickly and reliably sent to the monitoring centre or base station.

Thirdly, depending on the resources, it might be necessary to trade off these two requirements. So the routing protocol needs to be reactive and robust but in the face of given events, the routing protocol may choose to trade

between these two requirements. The rest of the paper is outlined as follows: Section 2 further explores the problem definition. Section 3 details a solution approach. Section 4 looks at proposed changes to support reactivity by enhancing the Ad-hoc on-Demand Distance Vector, (AODV), Protocol. Section 5 examines how this system can be made more reliable. Section 6 looks at the implementation environment. The paper concludes in the Section 7.

II. PROBLEM ANALYSIS

Figure 1 shows the wireless sensor network being deployed over a large geograhical area. Each node is able to measure the amount of soil moisture in the ground as well as detect the presence of rain. The latter is necessary as the amount of soil moisture may not be enough to detect the presence of rain. In addition, the system must quickly react in order to discover over which part of the sensor network is experiencing the event: in this case rain. When rain is detected as falling in a given part of the system, the data must be collected from the relevant nodes and sent to a central administrative server or base station. This means that it will be necessary to change the routing so that information on the change in the soil content in the affected area could be sent to the server as quickly as possible. This data should be routed at a higher priority that other information being sent. The key thing to note is that these changes must be dynamically setup as there will be little foreknowledge involved and so changes in the normal routing protocol are necessary to facilitate this. Hence the need for reactivity at the routing level.

Wireless systems are prone to errors associated with the environment in which these systems are deployed. Harsh environments such as very dry conditions can affect their performance and these systems must be carefully tuned to overcome environmental hindrances. However, this also means that a severe change in the environment such as going from a situation when it is dry to a situation when it is raining, sometimes very heavily, will likely affect how these wireless nodes operate and may introduce more errors. It will therefore be necessary to boost the reliability of the system to ensure that the required information reaches the server. Furthermore, depending on the amount of rain being experienced, the amount of data moving towards the central server may be substantial and could overwhelm certain links. In this context, some management of information flow may be necessary. Hence, there will be the temptation to remove all redunancy from the data, but given the fact
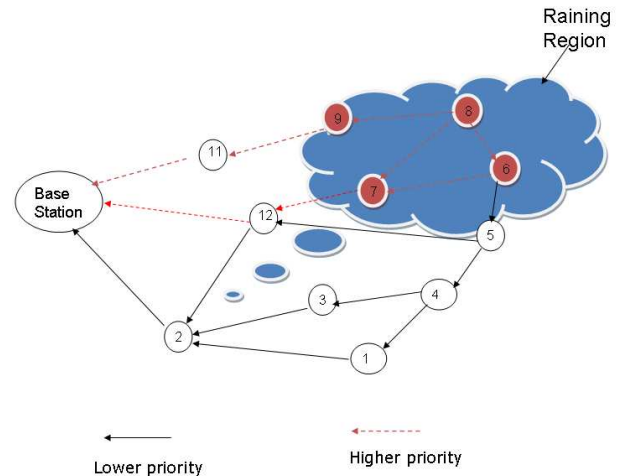

Fig. 1: Sensor Network Measuring Moisture

that reliability is needed some redundancy of the data is in fact recommended in this context. So a balance must be achieved and maintained.

Finally, there are energy considerations as Wireless Sensor Networks need access to power which must be carefully managed in outdoor environments. A lot of analysis of energy and power management have to do with careful scheduling of activity to maximize battery life. As in this study, the need for careful power management is lessened with the use of solar-powered WSN nodes; but the problem does not entirely go away. In the given scenario, a lot of data will be sent when a wireless node is in a rain-affected area and hence a lot of power could be consumed at this time. So the wireless node may have to balance between the power left and the information being sent. In addition if such a node is also routing information from other nodes, it may be necessary to decide which information stream is more important in order to convey the information required to give the *Big Picture*.

III. SOLUTION APPROACH

Having defined the issues we need to look at solution approaches.

A. Developing an event-driven reactive protocol

The first is the need to look at developing a reactive routing protocol. Since it is difficult to develop one from scratch, a better approach would be to tailor or enhance a well-known one. The Ad-hoc on-Demand Distance

Vector (AODV) Protocol [5] is a routing protocol designed for use in ad-hoc mobile networks. AODV is a reactive protocol: the routes are created only when they are needed. It uses traditional routing tables, one entry per destination, and sequence numbers are used to determine whether routing information is up-to-date and to prevent routing loops.

An important feature of AODV is the maintenance of time-based states in each node: a routing entry not recently used is treated as though the entry has expired. In case of a route being broken, then related neighbours are notified. Route discovery is based on query and reply cycles, and route information is stored in all intermediate nodes along the route in the form of route table entries. The following control packets are used: routing request message (RREQ) is broadcasted by a node requiring a route to another node, routing reply message (RREP) is unicasted back to the source of RREQ, and route error message (RERR) is sent to notify other nodes of the loss of the link. HELLO messages are used for detecting and monitoring links to neighbours.

1) Related Work on AODV: Wireless sensor protocols for environmental monitoring comprise a huge area of research, however, most of the research attention has been focused the MAC protocol. Tang and Zhang [6] analyzed the robustness of the original AODV and AODV-BR and pointed out their shortcomings. Then they proposed the Robust AODV protocol, where the active route is maintained by locally updating active route information to 1-hop neighbours. Multiple backup routes are built and the highest priority backup route is switched to become the new active route when the current active route breaks or when it is less preferred [5]. Cardell-Oliver, Smettem, Kranz and Mayer [4] have described the design and implementation of a novel reactive sensor network for monitoring soil moisture and evaluated the reactivity, robustness and longevity of the network in the field. The Pinjar network meets the goal of providing useful data on dynamic responses of soil moisture to rainfall, however, recent work looked at designing techniques to improve the fault-tolerance of AODV [7]. The need for a more flexible approach which deals with both reactivity and reliability in an integrated manner is therefore essential.

IV. PROPOSED CHANGES TO AODV

The plan is therefore to enhance AODV to move towards supporting a dynamic event-driven system as detailed in this paper. The first issue is that AODV was developed for the Ad-hoc environment and so it is sensible to have one entry per destination. However,
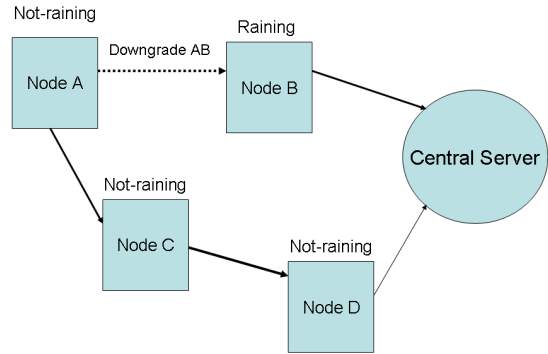

Fig. 2: Routing decisions made based on external events

since in WSNs most of the information exchange is between the sensor node and the monitoring station, we are therefore interested in multiple paths between the sensor node and the central server. Hence RREQ messages need to be changed to identify not just one route but several routes to a given destination.

Secondly, since routes may change due to the change in status of the individual nodes, it is necessary to allow HELLO messages to not just monitor links but to fully indicate the status of the node at the other side of the link. So in this case, HELLO messages would also indicate whether or not it is raining on the other end, the network load as well as the power left in the system. A key piece of data is whether or not a node is able to route data on behalf of other nodes. As we have said before, if a node is at the centre of a downpour, its data is probably more important than the data of its neighbouring nodes so it should not route data on behalf of these nodes. In such a situation, the node should also not respond to routing request (RREQ) messages.

Thirdly, though HELLO messages will be sent periodically, it is necessary to have another message type which can be sent immediately in response to sudden environmental, link, or node changes. These messages are called STATUS_CHANGE messages and are broadcasted to the entire system. For example, when a node first detects rain, it will broadcast a STATUS_CHANGE message which is picked up by other nodes. By storing this information from various nodes, it would be possible to detect where the rain is falling in the sensor network.

STATUS_CHANGE messages will cause routes to the central server to be re-evaluated. For example, if a node say A that is not affected by rain was using a route to

the central server via another node B, say; but now node A receives a STATUS_CHANGE message from node B saying that it has detected rain, then node A, which is not rain-affected, should no longer send data through node B if possible, since the data being generated by node B is more important. Node A should look for another route back to the server using other non-affected nodes. This would suggest that routes may have priorities based on the importance of the data being routed relative to the data being generated. In this case, node A will downgrade its route through node B, resulting in other routes through non-affected nodes being favoured. This is illustrated in Figure 2.

If rain is detected by both nodes, A and B, both nodes will send each other their absolute measurements as well as relative changes in the soil moisture content. Nodes with less relative soil moisture content changes which indicate less rain will downgrade routes through regions with high relative soil moisture content changes. So data will be routed away from the most rain-affected areas to the least rain-affected areas.

V. DEALING WITH RELIABILITY

As previousy pointed out, the system must not only be reactive but must also be robust in the face of changing environmental conditions. One of the ways of looking to provide support for robustness is to look to exploit multiple routes between the sensor node and the central host. So the idea is to analyse the routing algorithm to discover multiple routes between the sensor node and the host. In this context, non-overlapping routes will obviously be favoured.

A node that has critical data to send may do so by sending the data along two or more routes. So in this case packets that are from heavily rain-affected nodes could be sent along different routes while packets from non-affected nodes would only use one route. Again such routes would be affected by STATUS_CHANGE events and will be re-calculated as STATUS_CHANGE messages are received by the central server and the sensor nodes.

The use of different routes means that a connection between the sensor node and the central server is very similar to the idea of devices having multiple interfaces and using one or more interfaces to communicate with each other. There has been a lot of research into managing devices with multiple interfaces. The Stream Control Transport Protocol, SCTP, [8] has been developed and deployed to support these environments where there are multiple interfaces and hence multiple routes between
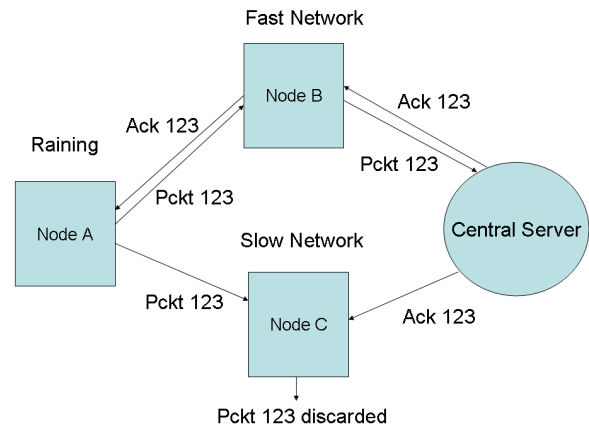

Fig. 3: Removing Redundant Packets from the Network

devices. Recently the IETF started a new initiative to develop Multipath TCP [9] in order to increase the connection bandwidth between end-devices.

A. Using Multipath Algorithms to Improve the Robustness of the Wireless Sensor Network

What we are proposing is that sensor nodes periodically send RREQ messages to determine different routes to the central server. When there is no rain, the sensor node sends its data back via one of these routes or may choose to balance the traffic amongst the different routes. When the sensor detects that it is raining, it then begins sending the same data on multiple routes to ensure reliability. The sensor nodes will be equipped with multiple radio technologies such as GSM and Zigbee so that multiple routes will be available.

However, there are enhancements to be made to the Multipath algorithms to allow them to be used in this demanding environment. Firstly since power is important and must be controlled, it is important that redundant packets which have already been received by the central site be removed from the WSN as soon as possible. One of the quickest way to do this is to broadcast all acknowledgements on all routes between the sensor node and the central server. Intermediate nodes will store the last acknowledgement for each connection. The sequence numbers of packets being forwarded will be checked against the acknowledgements received from the central server. If the packet has already been received via another route, then it is discarded. This sequence is shown in Figure 3.

Secondly, in order for this to work well, it is necessary to be able to quickly adjust routes when STATUS_CHANGE messages are received. So the algorithm

must be able to quickly converge to detect and exploit new routes. Finally, the ability to send over multiple interfaces will also be affected by the amount of power available to the sensor node at any given time. Thus a node may not be able to send the same packet over several routes because of power considerations. In this case, it would be necessary to determine the most reliable route to use.

VI. IMPLEMENTATION ENVIRONMENT

A. Current Work

Work has already been done studying the AODV algorithm using NS3, a well-known simulation package. The reactive protocol will be developed and tested using this environment. Changes will be made using the C++ programming language and performance results will be generated.

B. Towards a WSN Testbed

In addition to the use of simulation, an experimental testbed is being set up in Jordan to evaluate the solution approach outlined above. The hardware for the sensor node consists of a Vegetronix VG400 Soil Moisture Sensor, ZigBee Module, Socket Regulator for ZigBee, ZigBee Explorer, EasyPIC6 Development System, PIC16F887-I and a GSM Interface. In this project the use of GSM is proposed as it is widely available in the region where the testbed will be built. There is a solar collector which is used to power the board. The testbed will explore different power management systems to optimize the use of solar power to support the new routing protocol. The board will be controlled by an embedded OS [10] [11]. Finally, there is also a PC which acts as the central controller of the system. The setup is shown in Figure 4.

VII. CONCLUSIONS

In this paper, the design and development of a dynamic event-based routing algorithm was explored. The outlined design consists of developing support for reactivity using an enhanced version of AODV. Adding reliability may be done by adapting SCTP or Multipath TCP. These algorithms will first be investigated using NS3. They will then be implemented on an experimental wireless sensor network which is being developed in the Middle East.

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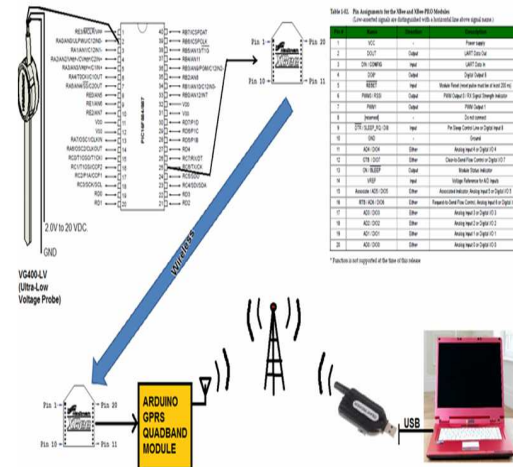
Fig. 4: Hardware for Sensor Node

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