Using a Grid-Enabled Wireless Sensor Network for Flood Management

Phil Greenwood, Danny Hughes, Barry Porter, Paul Grace, Geoff Coulson, Gordon Blair, Francois Taiani
Computing Department, InfoLab21,
South Drive, Lancaster University
Lancaster, LA1 4WA, UK.
danny@comp.lancs.ac.uk

Florian Pappenberger, Paul Smith, Keith Beven
Environmental Science Department,
Lancaster University,
Lancaster, LA1 4YQ.
f.pappenberger@lancaster.ac.uk

ABSTRACT
Flooding is becoming an increasing problem. As a result there is a need to deploy more sophisticated sensor networks to detect and react to flooding. This paper outlines a demonstration that illustrates our proposed solution to this problem involving embedded wireless hardware, component based middleware and overlay networks.

Keywords
Grid, overlay network s, components, sensor networks

INTRODUCTION
Flooding is an increasingly serious problem, especially as population pressures lead to increased building on flood plains. Currently, hydrologists deploy sensors at sites susceptible to flooding to record data such as water depth and rate-of-flow. The sensors are deployed statically and sensor data is fed off-site (e.g. using GSM) to grid-based computational models which predict both short and long term flooding trends [1,2]. We see considerable room for improvement in such scenarios. In particular, we propose employing a far more dynamic and autonomous sensor network organisation, and propose (selectively) shifting the execution of the prediction models to the sensor network itself which acts as a mini-grid. This more sophisticated approach promises several benefits. First, the approach can reduce the time hydrologists need to spend on site by increasing the survivaibility of the sensor networks in case of node of communication failures. Second, locally-computed predictions can be used to dynamically reconfigure the sensor network to optimise it for current environmental conditions (e.g., the network can employ a low power, low throughput organisation in quiescent conditions; and switch to a high power, resilient, high throughput organisation when flooding is imminent). And, third, it can be used to directly inform local stakeholders of imminent flooding.

To achieve this vision we have developed a sensor network framework based on an appropriate combination of software and hardware. Our software is based on our previously developed component-based run-time reconfigurable GridKit middleware [4]. And our hardware platform is based on the embedded Gumstix platform [3] which offers a good trade off between computational resources (needed to run the prediction models) and power consumption. We call the combined hardware and software platform 'GridStix'.

GRIDKIT
The Lancaster developed GridKit provides the key functionality to develop Grid-applications: service-binding, resource discovery, resource management and security. It is based on our language-independent OpenCOM component model [5], with each area of Grid functionality being implemented as an independent component framework. As GridKit is component based, it is inherently configurable and extensible. A wide range of target deployments can be built by selectively combining component frameworks, either rich and complex, or basic and simple, as appropriate. In particular, minimal deployments can be developed that contain just the bare functionality necessary to perform a particular task. By removing unnecessary components in this way, and thus reducing the associated computation and storage requirements, it is possible to deploy GridKit on scarcely-resourced embedded platforms.

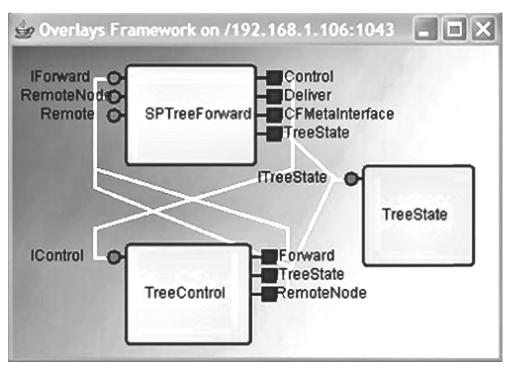

Figure 1: An Open Overlays Configuration

Of particular relevance to the proposed system is the *over-*

lay component framework. The overlay component framework is GridKit's core networking abstraction and provides a base for building application level networks (or overlays), which are typically used to implement services not provided by the underlying network, and to provide functionality that is outside of the scope of the underlying network. Classic examples include: resource discovery, content distribution event notification services, and spanning trees. Figure 1 illustrates a shortest path spanning tree implementation, which may be used to transmit sensor data offsite.

HARDWARE

As mentioned, the hardware used to host the GridKit platform is based on the Gumstix embedded computing platform—so named as each unit is roughly the same size as a pack of chewing gum. Gumstix are significantly more powerful than highly-embedded devices such as the Berkeley Motes [6]. Each unit features an Intel XScale CPU running at up to 400MHz, and comes equipped with 64MB of RAM, 16MB of flash memory and Bluetooth radio. 802.11b connectivity can also be added via a Compact Flash expansion card.

As might be expected, this computational power and flexibility comes at the expense of power consumption. During typical operation a Gumstix consumes up to 1 watt of power with a maximum theoretical power draw of up to 3 watts. This is not a significant problem in our target domain, however, as it is quite feasible for these power requirements to be met using a mid-sized solar panel and high-capacity battery.

SYSTEM OVERVIEW

As described previously, GridStix nodes are capable of maintaining both Bluetooth and 802.11b network infrastructures. This is desirable as the two networks have quite different properties and one can be selected over the other to reflect changing conditions or failures in the network. For example, a set of nodes in close proximity may be disseminating data between themselves in a multi-hop fashion via a low power consumption Bluetooth network. However, a critically placed node in this network could fail, resulting in network partition. To allow the sensor network to continue operating smoothly, our software infrastructure allows a sub-set of the nodes should then switch to 802.11b (due to the improved range) to repair the partition. Additionally, the type of data being disseminated through the sensor network can affect the decision on the network type to use. For example, to detect rate-of-flow in a rising river, we employ an image analysis algorithm to identify and track naturally occurring tracer particles on the water surface. Individual nodes are able to detect very coarse-grained changes in surface velocity; however, for more precise measurements to be performed, images need to be distributed to a number of nodes. As a consequence, the GridStix will switch network type from Bluetooth to 802.11b as Bluetooth does not have sufficient bandwidth to distribute the large image data-set in a timely fashion.

Adaptations in the sensor network can also take place at the overlay/spanning tree level, in that different overlays can be substituted at run-time depending on the environmental conditions. The GridStix nodes might initially be structured using a shortest-path tree. As 'shortest path' corresponds to the distance between nodes, it correlates with the amount of power necessary to reliably transmit data between nodes, resulting in a power-efficient topology. However, trees of this nature tend to be 'skinny' which reduces their resilience to failure. When flooding is predicted it is therefore desirable to increase resilience to failure rather than conserve power. As a result, a fewest-hop tree can be dynamically substituted, thus increasing system resilience. Fewest-hop trees tend to produce 'fat' topologies with each node having fewer children. This means fewer nodes are affected when one particular node fails. Example shortest path and fewest hop spanning trees are shown in Figure 2.

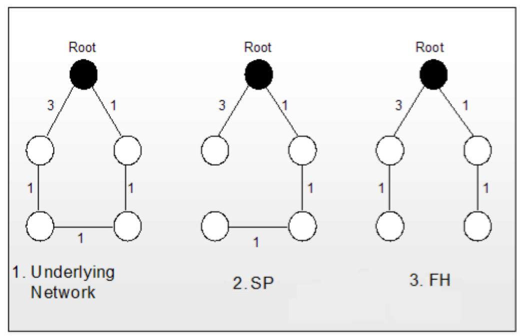

Figure 2: SP and FH Spanning Trees

SUMMARY

This paper has given a brief overview of how we have combined embedded hardware and a component-based Grid platform to offer improved support for flood prediction. This combination allows the sensor network to be adapted in rich ways to best suit the current and future environmental conditions. This increases the utility, the resilience and the performance of the network.

REFERENCES

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DEMONSTRATION SUPPLEMENT

CONTACT INFO

First Name	Danny
Last Name	Hughes
Organization	Lancaster University
Street Address	Computing, InfoLab 21, South Drive, Lancaster University,
City	Lancaster,
State/Province	Lancashire.
Country	UK
Postal Code	LA1 4WA
Daytime Telephone	+44 (0) 1524510351
Email	danny@comp.lancs.ac.uk
URL	Demonstration Video Supplement: http://www.comp.lancs.ac.uk/computing/users/hughesdr/DemoVideo_Final.wmv Project Web Site: http://www.comp.lancs.ac.uk/computing/users/hughesdr/nwgrid/

DEMONSTRATION DESCRIPTION

Title: GridStix: A Grid-Enabled Wireless Sensor Network for Flood Management

Project Description (100 words max):

The GridStix demo uses a mixture of physical props and on-screen visualizations to illustrate how a GridStix-based wireless sensor network, deployed to perform flood monitoring, adapts its behaviour to best suit changing environmental conditions.

Envisioned Interaction:

Ubicomp attendees will see a table at approximately waist height supporting a display box that is 75cm long, 60cm wide and 15cm deep. On the front of this installation are the project logos, while on the top is a printed satellite map showing the deployment site (a river valley in the north of England). GridStix sensor nodes are 'deployed' on this map to reflect their locations in the real-world deployment. This is shown in Figure 1.

Figure 1 – Demo Installation.

Figure 2 – Network Visualization

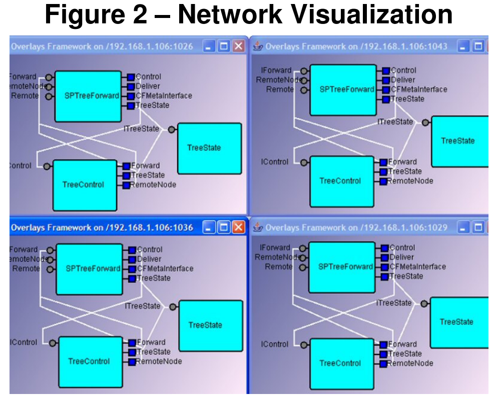

Figure 3 – Component Visualization

The physical installation is accompanied by two on-screen visualizations. The first (see Figure 2) shows, in real-time, the overlay network topology being maintained by the GridStix nodes. This will be displayed on a 19" LCD monitor. The second visualization (see Figure 3) shows, in real time, the current software component configuration on each GridStix. This will be displayed using a projector immediately above and behind the installation.

Following a brief introduction to the relevant hardware and software technologies and the deployment site, users can interact with the installation by simulating changing flood conditions as discussed below.

The **first user interaction** is as follows: *In the real-world*, initial detection of high-flow conditions in the river causes the GridStix nodes to reconfigure from using a low power Bluetooth network to a high performance 802.11b network suitable for supporting distributed image-based flow-rate measurement. *In the demo*, users are invited to simulate fast flow conditions by rolling marbles down the shute located at the upper-right hand corner of the installation (see Figure 4). The motion of the marbles is detected by a network camera and this causes the GridStix to perform the above reconfiguration. The reconfiguration is reflected in real time by the network visualization (shown in Figure 2). When the user stops rolling marbles, this simulates river flow returning to normal conditions and the GridStix switch back to the Bluetooth network, which is again reflected in the network visualization.

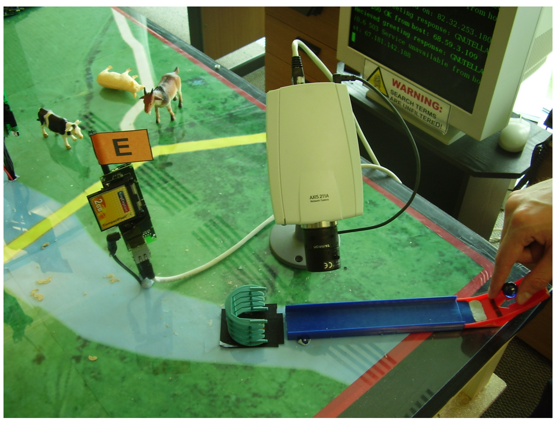

Figure 4 – Simulating High Flow

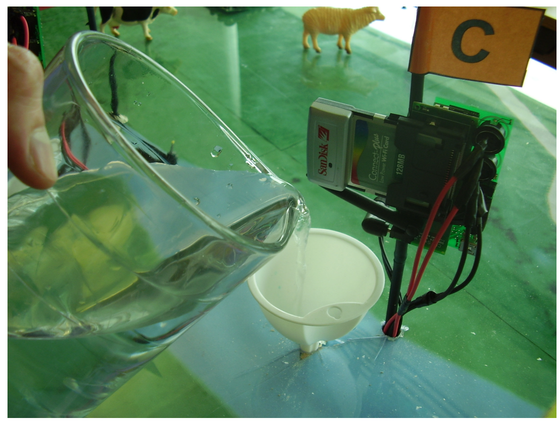

Figure 5 – Simulating a Flood Risk

The **second user interaction** is as follows: *In the real world*, flood risk is assessed based on water depth sensors informing a 'point-based' flood prediction algorithm executed on a 'cluster' formed from the collected computational resources of the GridStix nodes. Increased flood risk causes the system to adapt the overlay tree being used to support communication between the nodes. In particular, the configuration changes from using a low-power shortest-hop spanning tree to a more reliable fewest-hop spanning tree by swapping the 'forwarding' component of the 'overlay' component framework running on each node. *In the demo*, users are invited to pour water into one of three funnels located in front of the GridStix (see Figure 5). This triggers a water sensor, which causes the Gumstix to perform the above reconfiguration. This is reflected firstly in the component visualization (see Figure 3) which shows the forwarding component of a shortest path spanning tree being swapped for the forwarding component of a fewest hop spanning tree. Secondly, it is reflected in the network visualization (see Figure 2) by showing the rebuilding of the tree to conform to the fewest hop topology. Following this adaptation sequence, users will be invited to continue adding water, which, at a set level, simulates the GridStix node failing due to immersion. This again will be reflected in the network visualization as the node is removed from the network topology .

A video supplement showing this demonstration in action is also available at:
http://www.comp.lancs.ac.uk/computing/users/hughesdr/DemoVideo_Final.wmv

TECHNICAL REQUIREMENTS

SPACE

The demonstration will require a table with a minimum size of 80cm wide, 60cm deep and preferably not more than 80cm high. An additional few meters around the front and sides of the table would be required to allow people to watch and interact with the demonstration. A second table of similar height will also be required to accommodate the projector.

ACOUSTICAL

The demonstration has no special acoustical requirements and should not generate a great deal of noise aside from the demonstrator guiding attendees through their interactions with the installation.

LIGHTING

The motion detection used by the camera is vulnerable to reflections from the table's clear plastic coating in very bright light conditions such as bright sunlight; however, this is not an issue in normal indoor lighting conditions.

TIME

The demonstration may run throughout the conference, though a demonstrator is required to be present to guide attendees through their interactions with the installation. The demonstration works best with small groups of up to 15 people, from which two people will typically be asked to perform the interactions described above. The complete demonstration sequence, including each of the interactions described above, takes between 5 and 10 minutes excluding questions. Ideally, another 2 – 5 minutes is required between demonstrations to re-initialise the system.

COMPUTATIONAL EQUIPMENT

The demonstration involves custom embedded hardware and sensors, all of which we will provide. Additionally, two standard PCs are required to drive the visualizations. We can provide both PCs; however, if one is available at the conference site, this would be useful in reducing the amount of hardware we need to transport. We only require that this PC be of a reasonably modern specification and have a java-enabled web browser installed. We can provide our own projector; however, if one could be provided for us, this would again be useful.

NETWORKING

The demonstration installation maintains its own ad-hoc Bluetooth and 802.11b wireless network infrastructures and we do not need connection to the Internet.

RADIO FREQUENCIES

The demonstration uses standard power Bluetooth and 802.11b radio hardware at the normal frequency ranges. Within this frequency range, we can configure the 802.11b to any unused channel.

POWER

We will be providing all power adapters and necessary extension cables; therefore we require only two power outlets, within 2 meters of the demonstration installation.