A SELF – SYNCHRONISED SCHEME FOR COMMUNICATION IN WIRELESS SENSOR NETWORKS

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ABSTRACT

An algorithm for self-scheduling of access for wireless devices and seamless discrimination of routes to data collectors for sensor networks is described. The proposed algorithm relies on the robustness and stability of the self-synchronisation of pulse coupled oscillators. In order to confirm this assumption an experiment is set up for evaluating its performance. Initial results indicate a positive response to low levels of mobility and noise. Initial experiences are mentioned and future steps are drafted.

I   INTRODUCTION AND MOTIVATION

A typical sensor network wirelessly interconnects a collection of sensor nodes for the purpose of collection of data. Sensor nodes are exposed to natural elements and consequently vulnerable to be displaced from their initial intended location. As a result of having their sealed casing, available resources for their operating life are determined at the moment of deployment. Consequently, they rely on limited computational resources. Because of their location and additional requirements, nodes playing the role of gateways may have additional resources than the rest. Since wireless devices attached to sensor nodes have a limited transmission range, hop based communication is needed to flexibly cover vast areas without recourse to a fixed communication infrastructure. Crucially, sensor networks must operate autonomously with no demand for manual reconfiguration.

Intermittent long latency channels to data collectors and external conditions make self-reliant lightweight techniques crucial to achieve robustness. Four aspects are particularly considered. Firstly, overheads caused by explicit setting-up, maintaining and cancelling of communication paths to data collectors, acknowledging transmissions, and confirming message exchange need to be greatly reduced. Secondly, because of the complexity of handling a large and dynamic number of active devices, communication protocols should avoid relying on addressable-endpoints. Thirdly, eliminating excessive buffer management is needed. Lastly, achieving a high rate of message arrival is considered of high relevance in consideration of the inherent redundancy. The required typical bit rate is low compared to other wireless applications if imaging is not involved, reducing pressure on bandwidth demands. Scheduled schemes are known to provide sustained data throughput with low penalties for handling multiple simultaneous contenders. The associated network must dynamically self-reconfigure functional routes as needed. Using a scheduled fashion of wireless access brings predictability and cooperation to sensor nodes.

In order to enable the data collection with the characteristics described above, this proposal aims to provide self-scheduling of access for wireless devices and discrimination of routes to data collectors. We are proposing a self – synchronisation algorithm simple enough to be implemented in the targeted platform with properties of durability and resilience.   The proposed algorithm takes its foundations from previous work on self-synchronisation of discrete coupled oscillators; which indicates that given a certain set of conditions, a group of oscillators will retain their phase – synchronicity. For demonstrating that the proposed algorithm possesses similar properties, an experiment with application to environmental monitoring is setup and its results discussed.

II   RELATED RESEARCH

Properties of self-synchronisation of pulse-coupled oscillators have been extensively studied by Strogatz in [1] and [2]. Applications in different fields include the use of self-synchronisation of oscillators for performing coherent perception using discrete dynamics elements as in [3]. The authors of [4] use theory and methods applicable to pulse coupled oscillators for proposing a service of global time synchronisation with high levels of accuracy and robustness in ad hoc networks. Nevertheless, its scope is focused on providing accurate time service, leaving space for further understanding of similar techniques for different and wider scenarios. [5] discusses the process of dynamic cluster formation using a population of pulse-coupled oscillators firing at a predetermined phase difference. It seems clear that there is space for further research taking in consideration the peculiar application requirements.

Relevant research indicates that reduced-state protocols can achieve interestingly high levels of resilience and performance. In [6], specific properties of a mechanism for simple propagation of routing information in ad hoc networks are discussed. It introduces valuable references and insights of how similar proposals could perform on similar conditions; however, it is short of reaching further conclusions related to specific issues applicable on environmental observation. The use of scheduled schemes in favour of on-demand schemes for sensor networks has recently attracted specific attention. [7] discusses the use of a non-persistent spatial TDMA technique with advantages in energy consumption for transport regular and frequent traffic. [9] discusses the relevance of

further study on oceanographic monitoring using collegiate sensor networks; in its discussion, mentions the importance of establishing strong experimental experience.

III   PROPOSED MODEL

The sensor network is modelled as a set of identical oscillators interconnected by the ability to synchronise their firing pulses. Defining hop depth as the number of hops needed to reach the closest data collector using the shortest path available, the network aims to converge to a state where the groups of devices belonging to the same hop depth become phase synchronised with respect to groups belonging to the upper and lower hop depths. The converged state of the network assembles a synchronised chain on which the structure of "firing" and "observing firing" is well structured. The direction of the chain is towards data collectors.
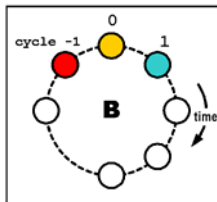

The oscillators are characterised by a time-state variable that monotonically increases until a threshold is reached. When this happens the oscillator releases a pulse visible to other oscillators. The pulsing oscillator then returns to its basal level for initiating a new cycle. This metaphor is illustrated in

Figure 1 using a circular representation of time elapsed in the oscillator. From the number of "steps" available in the oscillator only three are dedicated to network interaction with assigned activities to be performed on them. Oscillators reaching the position *0* will fire, when in position (*cycle – 1*) and *1* (first step after firing) will look for other's pulses. In the position (*cycle – 1*) the device will intend to observe pulses originated from one hop depth higher than its own. In the position *1,* it will intend to observe pulses originated from one hop closer to the data collector.

Figure 1. A metaphor of oscillator of discrete steps is used for keeping track of the specific activities in the operational cycle.

A discrete automaton of two states (*induced* and *not-induced*) controls the dynamics of the oscillators. The pseudo-code for the general algorithm is Figure 3 and Figure 2.Oscillators compare their current phase with the presence or absence of other's pulses using those two states; as a result they transit from one state to the other. During the default state, *not-induced*, oscillators dedicate cycles in detecting other's pulses and abstain of firing. If satisfied with a persistent signal will then phase their time-state to the appropriate value and transit to the *induced* state. During the induced state, the oscillators will fully perform their regular routine until they transit back. For implementing the transitions between states, a sliding window technique is used. The parameter *inducement-threshold* represents the number of observed pulses in recent cycles needed for transiting to the induced state. Similarly, the parameter *not-inducement-threshold* represents the number of missed pulses required for causing a transition to the not-inducement state.

By using this model, nodes in a sensor network reaching the induced state remain absent of network activity until they approach the appropriate steps on their internal oscillators. When in position (*cycle – 1*) they will receive messages for forwarding and when in *1* they will forward them. When in position 0 they will transmit. The dynamics of the algorithm establishes the scheduling order and routing.

```
begin induced-state
  if pulse visible
     record it at j[running-step]
  else
    if running-phase = first phase after firing
       set signals-missed 1 + signals-missed
       if signals-missed > not-inducement -threshold
         set running-phase cycle – ( 2 * step )
         set state not-induced
   running-phase running-step + step
end
```

Figure 3. Pseudo code for the induced state

```
begin not-induced state
  if pulse visible
    record it at i[running-step]
    if running-phase = cycle - step
      if i[] is not empty
          set signals-received signals-received  + 1
          if signals-received > inducement- threshold
            set preferred-phase latest pulse at i[]
            set running-phase cycle - preferred-phase
            set state induced
  set running-step running-step + step
end
```

Figure 2. Pseudo code for the not-induced state

IV   EXPERIMENT IMPLEMENTATION

A scenario of 48 devices and one base station with identical pulse range of circular shape and a radius of 8.5 units was simulated using the agent based simulator Netlogo [8] over a squared deployment area of 61 by 41 units. Motion was simulated using Brownian trajectories (nodes move a random distance of 0% - 0.5% of the simulated pulse range per time unit. Noise was simulated by affecting 2% of pulse reception at every oscillator. The firing pulse lasts one time unit; 10 time units constitute the operational cycle. Inducement threshold was set to 1 and not-inducement threshold was set of 2.. Nodes are initially randomly placed across the working area whilst keeping initial average network density (a function of transmission range and number of nodes over the

working area); however, it is expected that nodes will move freely through the period of the experiment. Thus, network density will vary over different sections of the working area. Each device is provided with identical code and randomised initial values (between zero and the length of the cycle) for their internal time-states. The simulation was run for 100 cycles.

IV.1 SUB-EXPERIMENT: PERTURBING THE DEPLOYMENT
In order to make a quick assessment of the resilience of the algorithms to unexpected events a second experiment is implemented. When the universal time reaches 100 time units, 10 nodes from the population are randomly selected and their synchronisation details reset. The network response is analysed.

IV.2 EVALUATION METHOD

The scheduling scheme is evaluated using the number of pulses that occur undetected by potential receivers (a). This indicates that devices are inappropriately synchronised with their vicinity. Routes must have close similarity to the shortest path to data collectors; consequently, routing is evaluated by analysing the difference between the computed hop depth of the nodes firing and the computed hop depth of the nodes listening for forwarding purposes. A difference of one represents a successful engagement; a higher difference indicates additional hops than the minimal. The statistical variance of the values collected for this measurement, every time unit, is used as indicator (b). The number of nodes in inducement state is a good indicator of stability of the algorithms (c); transiting to not-induced can be seen as a self-healing mechanism.

V   INITIAL RESULTS

Results are plotted in the Figure 5 and Figure 5 X axis plots time (using cycles as units) elapsed from the beginning of the simulation. First left Y axis plots (a) and (b); right Y axis plots (c). Noise and mobility settings are indicated in their respective captions. It is expected that noise affecting the network have stronger impact on missing pulses (a) than it would have for route efficiency (b); similarly, mobility has stronger impact on (b) than it is for (a).
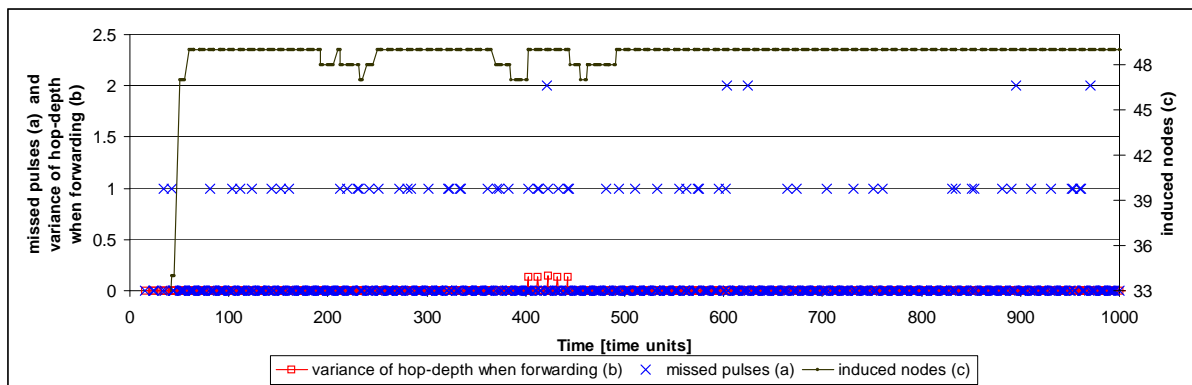

Figure 5. The graph illustrates the performance of the algorithm for a 49 node sensor network. It can be seen that besides the period between 400 and 450 time units, the network achieve high route efficiency. This particular period can be explained by the mobility of one of the nodes since (b) remain relatively low. It can also be seen that transmitters keep a stable synchronised operation for the duration of the experiment
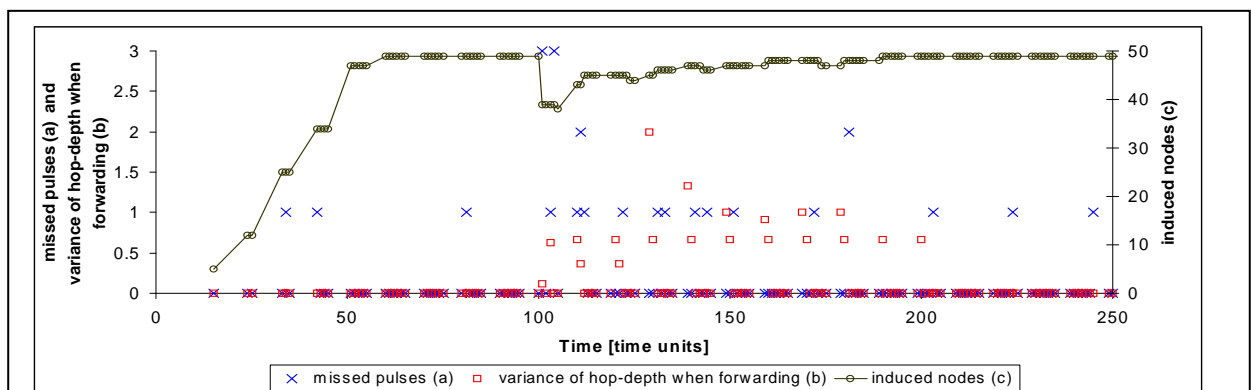

Figure 4. The graph illustrates the initial convergence process and the effects of resetting 10 nodes by random selection at time 100. It can be seen the immediate effects of removing and joining the ten nodes. It can be argued that by 200 time units, the main effects have been absorbed.

From the results, it can be seen that missed pulses (a) are present in small numbers and scattered across the experiment. Their effect on the induced state nodes is limited due to the natural redundancy of the links and their reduced persistence for the same nodes. It also can be seen that the variance of hop depth gradient (b) for evaluating routing is present in bursts. Changes in topology due to mobility make persistent routes inefficient; and depending on the hop depth where they occur have different effect on the value of (b). Thus, an additional hop in the route occurring at hop depth 1 is likely to propagate this deficiency until it is repaired.

VI CONCLUSIONS AND FUTURE STEPS

The presented results indicate that the proposed method can be used for resilient networking in wireless sensor networks. Initial convergence from random state occurs with no apparent difficulty. It can be seen that despite the presence of noise and limited mobility disturbing the connectivity of the network, the algorithms allow the network to recover gracefully its capacity. In addition, the algorithms are simple enough to be implemented in resource-limited devices. The device population seems to successfully self-organise the scheduled order of transmissions and reception and high route efficiency is achieved. It is considered necessary to analyse the proposal under more realistic propagation and disturbing scenarios than those used for the preparation of this document. It is also considered relevant to research further the impact of different settings and thresholds on longer operation periods.

During the next months, the proposed method will be progressively tested for an environmental application as part of the project SECOAS in the Scroby sands area in the coast of Norfolk [9]. A PCB hosting a PIC MCU 16FXXX series with radio transceiver modules will be used as a platform for implementing the radio and network layers. Current challenges include developing further understanding of the bit error rate conditions at sea surface; and successfully detecting the timing characteristics in which an incoming transmission can be received.

Figure 6. Picture of the PCB hosting the initial platform for developing the radio and network platform for SECOAS. (Picture courtesy of Steve Fitz)

ACKNOWLEDGMENTS

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