OVER THE AIR PROGRAMMING (OTAP)

INTRODUCTION

Over the Air Programming (OTAP) is the ability to reprogram a Wireless Sensor Networks (WSN) as deployed without the requirement to collect or physically connect to every node. Methods of OTAP called code dissemination techniques strive for efficiency in power and time as well as reliability. Leading techniques such as Sprinkler, Firecracker, and Deluge each have their own advantages. This research simulates and compares these three dissemination techniques to gather data on time to reprogram randomly deployed networks of varying number of nodes.

APPLICATIONS

Fleet Monitoring Updates and Vehicle ECU Updates without Factory Recall

Product Monitoring Updates Specifically at Remote Storage Locations

PROPERTIES OF CODE DISSEMINATION TECHNIQUES

Point to Point & Broadcast

All dissemination methods operate by a combination of point to point programming to update individual nodes as well as broadcasts to spread an update to all surrounding nodes in range.

Arbitration

The arbitrator is the decision maker during the dissemination of code. Arbitration governs which nodes are to be point to point programmed and which nodes are to perform a broadcast. Different OTAP methods fall into two categories being Gateway Arbitrated or Self Arbitrating.

Paging

Paging is a technique used where a large section of code is split into a number of shorter pages. During a reprogram of a network individual pages can be transmitted and if lost can be re-transmitted without resending the entire code update.

Delta Updates

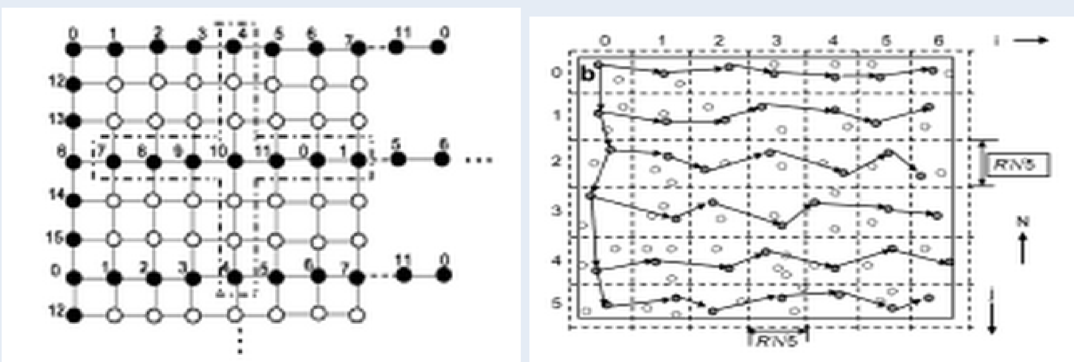
Delta updates is a technique used where only changes in program code are transmitted reducing the amount of total data to be sent and also the time required. If used with paging only a page containing an update would be required to be transmitted.

Broadcast Storm & Hidden Node

Broadcast storms and Hidden Nodes are both common problems during the running of dissemination techniques. These involve range overlaps in range causing nodes to be swamped by two transmitters or alternatively mutual exclusion of a node.

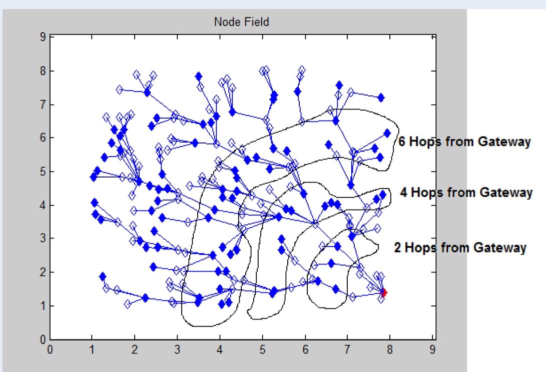
SPRINKLER

The Sprinkler Technique from the literature is designed to use point to point programming to generate complete rows of programmed nodes or at least one "Sprinkler Node" per zone in complex networks shown below. This however is designed to be used with localisation techniques so that this Gateway arbitrated dissemination method is aware of nodes locations.

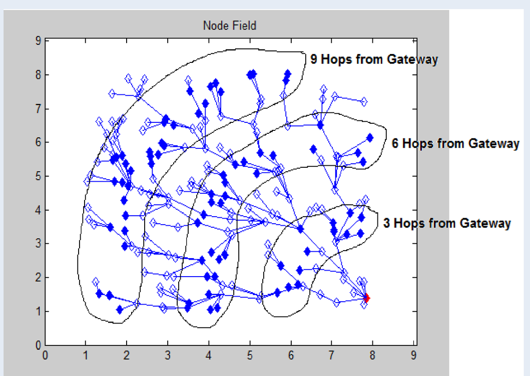


Sprinkler Methodology Diagram from Literature [1]

Sprinkler as run in the simulation utilised a number of hops based algorithm intended to generate concentric rings of programmed "Sprinkler Nodes" without the need for localisation.

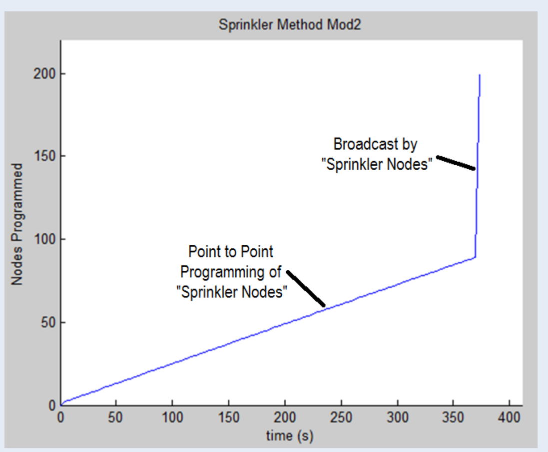


Sprinkler Mod 2 in Simulation

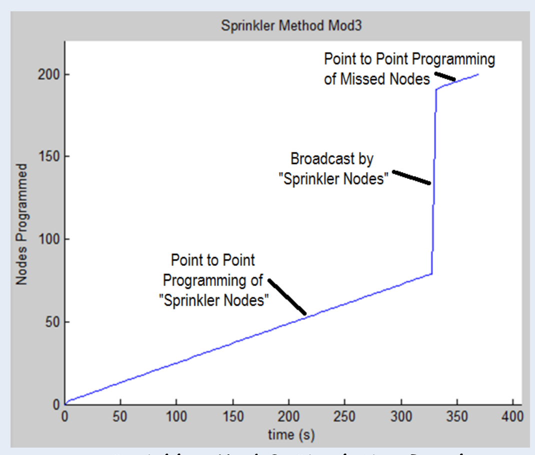


Sprinkler Mod 3 in Simulation

Both modulus 2 and modulus 3 based algorithms were tested resulting in every second layer of network hops away from the gateway being "Sprinkler Nodes" or every third layer of network hops being made "Sprinkler Nodes" respectively. The reasoning for this is Sprinkler Mod 3 requires point to point programming of excluded nodes once the algorithm has finished running where as Sprinkler Mod 2 does not. This can be seen in the result graphs generated for a run of both algorithms on the shown network.



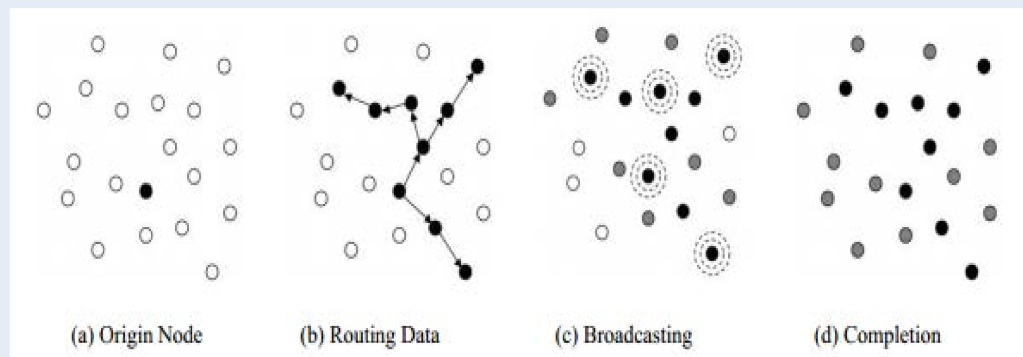
Sprinkler Mod 2 Simulation Results



Sprinkler Mod 3 Simulation Results

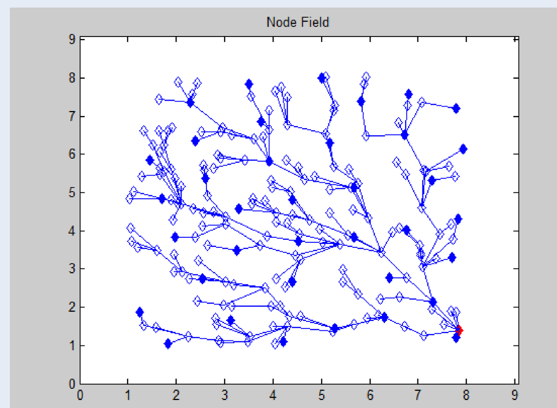
FIRECRACKER

The Firecracker Technique from the literature is designed to use point to point programming to generate "Firecracker Nodes" at locations with maximum coverage. These "Firecracker Nodes" once programmed all perform a local broadcast to cover the entire network with an update.



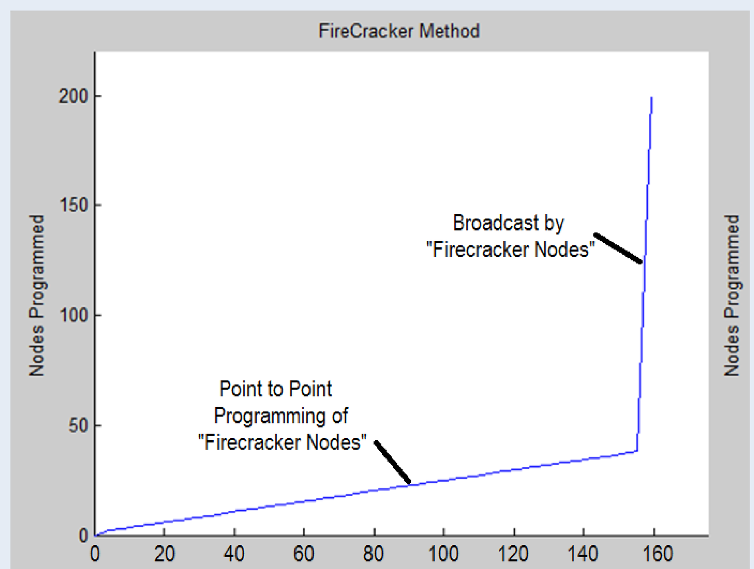
Firecracker Methodology Diagram from Literature [2]

Firecracker in the simulation is run almost identically to the literature. Decisions made on which nodes to select as "Firecracker Nodes" is done by repeatedly choosing nodes to be "Firecracker Nodes" followed by checking which nodes remain out of broadcast range of any current "Firecracker Node". Once complete the entire network is within broadcast range of at least one "Firecracker Node".



Firecracker Method in the Simulation with "Firecracker Nodes" Programmed

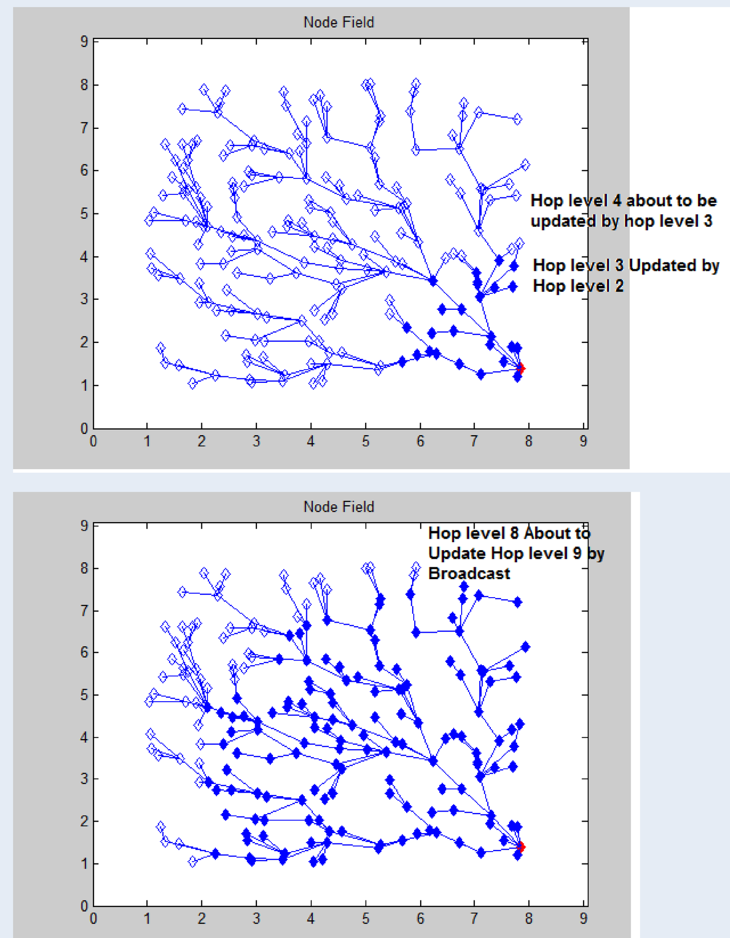
The results shown for the Firecracker simulation show the point to point programming of the "Firecracker Nodes" followed by the broadcast event to cover the entire network.



Firecracker Results from Simulation of Shown Network

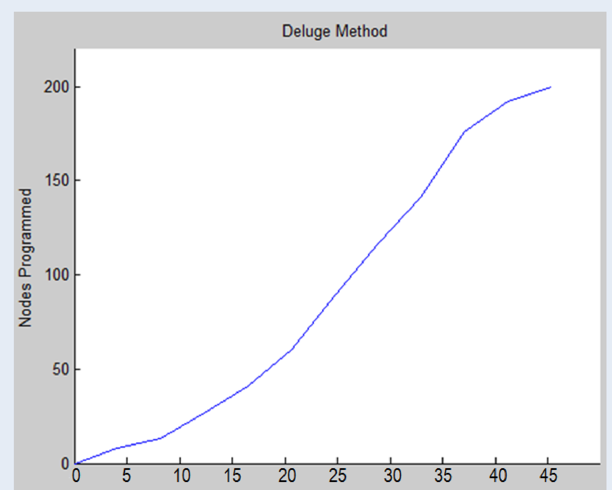
DELUGE

Unlike both Sprinkler and Firecracker which are gateway arbitrated, Deluge is a self arbitration dissemination technique. This means that each node is responsible for organising the point to point or broadcast programming of all the nodes around it. As this process starts at the gateway the resultant reprogramming of the wireless network has the appearance of a propagating wave from the gateway to the last branch of the network.



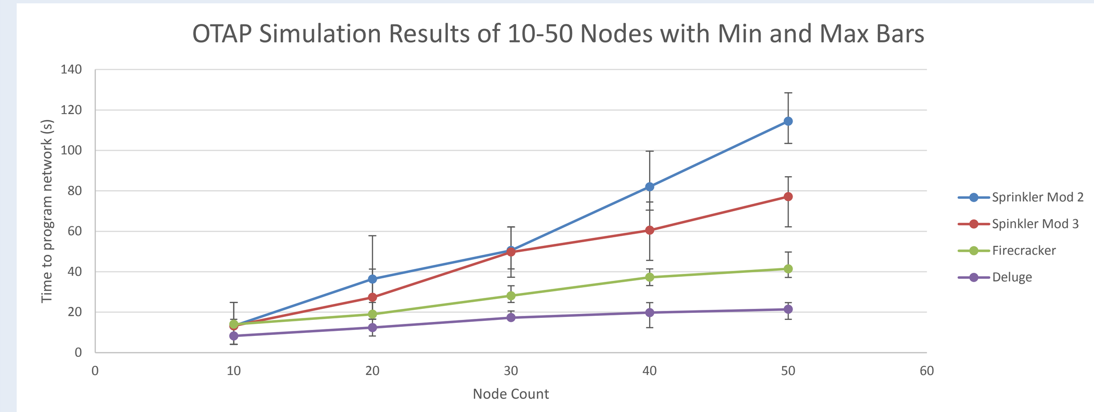
Snapshots of an Early and Late Stage of the Deluge Method During Simulation

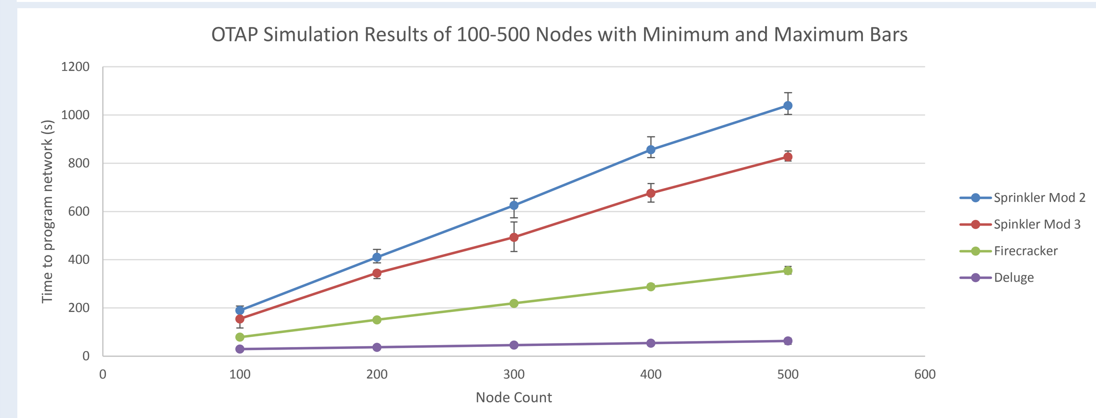
The results generated by the Deluge method tend to be more linear however in the early stages fewer nodes are programmed each program event. The middle stages of the network seem to gradually accelerate in nodes programmed per event as the propagation wave grows circularly to cover the network. Final stages of the result graph slows as only branches of the network that have a few extra hops are still running the algorithm.



Deluge Results from Simulation of Shown Network

RESULTS





The results show that each dissemination technique's time to program the network is almost directly proportionate to the number of nodes in the network regardless of the random layouts used. Furthermore the advantages in time of Deluge and Firecracker grow with the more nodes in the network. The maximum and minimum result variance in each test result remain almost constant and does not seem to grow with the more number of nodes simulated.

CONCLUSIONS

The Deluge method is obviously the best performing technique for wirelessly reprogramming a network. Firecracker would be a close second however it might be possible to gain further advantages over the deluge method by making a combination of Deluge and Firecracker. Future work involves expanding the simulation to focus on these two methods specifically as well as an attempted merger of both into a single more efficient code dissemination technique.

References

[1]. Naik, Vinayak, Anish Arora, Prasun Sinha, and Hongwei Zhang. "Sprinkler: A reliable and energy efficient data dissemination service for wireless embedded devices." In *Real-Time Systems Symposium, 2005. RTSS 2005. Miami, Florida. 26th IEEE International*, pg. 277 . IEEE, 2005.

[2]. Levis, Philip, and David Culler. "The firecracker protocol." In *Proceedings of the 11th workshop on ACM SIGOPS European workshop*, Leuven, Belgium. ACM, 2004.

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[4]. Wang, Qiang, Yaoyao Zhu, and Liang Cheng. "Reprogramming wireless sensor networks: challenges and approaches." *Network, IEEE* 20, no. 3 (2006): 48-55.