Class-Based Networking and Wake-Up Transceivers in Mobile Ad Hoc Asset Tracking and Monitoring

***Abstract:* A novel approach to track and monitor moving/movable assets using a Class-Based Networking (CBN) architecture and point-to-multi-point radios that employ wake-up transceivers is described. The combination of CBN and wake-up transceivers offers several advantages over other wireless networking technologies, including: dramatic increase in radio battery life (years); significant reduction in RF noise; use of standards-based radios (e.g., Bluetooth® and Wi-Fi); Mbps data rates; and radio transmission only when sending data (eliminating timer dependency and periodic "blinks"). CBN also enables the concurrent operation of multiple radio types, in multiple architectures, to multiple standards, in the same area, sharing the same infrastructure, yet operate independently in high-density environments, facilitating global application.**

Index Terms: Asset tracking, class-based networking, mobile ad hoc networking, sensor monitoring.

1. Introduction

Commercially available asset tracking systems are typically based on either:

- RFID tags, which require moving the tagged assets within a few feet of a fixed reader, or moving the reader within a few feet of the tagged assets, or
- GPS, which requires line-of-sight reception from multiple satellites, which limits system utility with assets that are indoors or in other obstructed locations.

The utility of currently available RFID-based systems is further limited by:

- Poor wireless security
- Lack of real-time alerting
- Limited data capacity
- Poor sensor integration capability
- High infrastructure requirements

The utility of GPS-based systems is further limited by:

- High consumption of battery power
- High costs, for device purchase and installation, and for system operating expenses
- Need for a separate data communications link to report asset position and/or to report sensor data.

Despite recent advances in ad hoc networking applied to asset tracking, tracking of large numbers of moving/ movable assets (1000s) and monitoring of large numbers of sensors attached to those assets still pose challenges. Section 2 of this paper discusses the use of CBN architecture and point-to-multi-point radios with wake-up transceivers, in self-forming networks to address these challenges. Section 3 of this paper discusses applications of CBN, these networks, and nodes with wake-up transceivers.

2. Class-Based Networking

A. Typical Mobile Ad Hoc Networks

Ad hoc networks support point-to-point (node-to-node) communications without central control. Wireless ad hoc networks support communications without being constrained by wires, enabling communications with nodes attached to assets as the assets/nodes move or are moved to new locations and in changing configurations. Consequently, wireless ad hoc networks can be deployed quickly and can adjust to the dynamic comings, goings, and re-positioning of assets/nodes, as well as to the continually changing RF environment.

Such networks tend to be relatively inexpensive, fault-tolerant, and flexible. However, commonly used random-access protocols and the design/selection of radios to support the networks are not well coordinated, often resulting in sub-optimized network topology and constrained applications. Further, such networks typically organize on the basis of physical proximity of the nodes or by received signal strength. All of these factors introduce added latency, reduced throughput, and increased (and avoidable) transmissions and interference. As more nodes enter the network, the impairments are aggravated, and with each added transmission, battery power of the mobile nodes is consumed.

Many of these impairments are typically addressed by adding more complex routing and management protocols, often following wireline-based Internet models. However, the additional complexity nearly always requires additional processing at each node to process the protocols, and makes the network more "chatty" in sending messages among nodes to put the routing into effect. The added processing and transmissions consume additional battery life, put more

RF into the air, and consume network throughput just managing the network.

B. Class-Based Networking

Class-based networking is a networking methodology patented by TeraHop Networks, Inc. (TeraHop). Using this methodology, wireless ad hoc hierarchical networks form using transceivers (in the nodes) that have a class designator assigned to them. In the TeraHop implementation, each node has a data transceiver that is a standards-based radio and a separate, low-power wake-up radio. In this implementation, rather than relying on complex routing protocols and incurring the associated penalties described above, simple protocols and class-based networking are employed, as described below.

C. Network Architectures

As described above, common wireless ad hoc networks form based on physical proximity and/or based on the effective radio range of the nodes. Only those nodes that are in radio range (which usually means they are physically close to each other) can communicate with each other and form a network.

Figure 1 shows this formation graphically. The nodes enclosed by each dotted-line perimeter comprise each network.

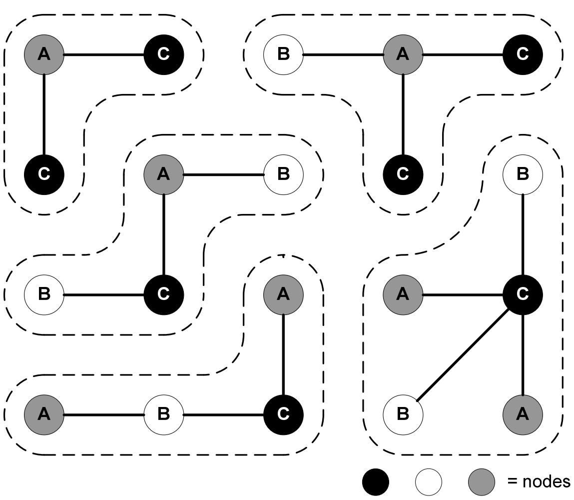

Figure 1.
Point-to-Multi-Point Networking
Connectivity is determined by proximity.

In contrast, a class-based network forms among those nodes that have at least one class designation in common. The nodes still must be within radio range of at least one other node of the same class, but other nodes that may be in close proximity but are not of the same class are ignored (and those other nodes ignore all nodes not in *their* classes).

Using the same array of nodes as in Figure 1, class-based networking is shown in Figure 2. Those nodes that are connected by a line (e.g., all As) communicate and form networks among themselves.

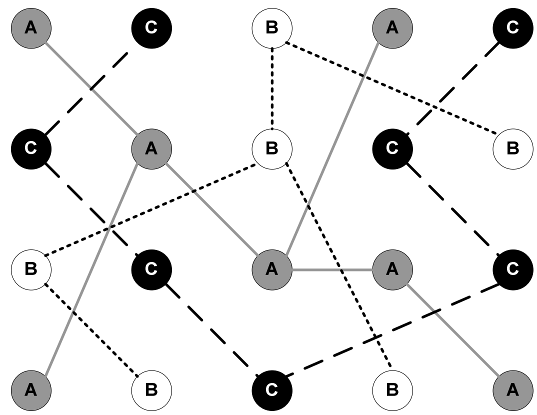

Figure 2.
Class-Based Networking
Connectivity is determined by class designation.

D. Wake-Up Transceivers

Although transmissions from wireless nodes can consume much battery power, it is the nodes' receivers that usually limit battery life. Ordinarily, nodes' receivers are always on, in order that any node can receive a transmission from any other node, at any time. Since these receivers are usually matched in sophistication and capability to the transmitters from which they receive data, they drain much current from the node's batteries. Even when these sophisticated receivers are cycled on and off, reducing their average current drain, battery life is still measured in days or weeks, unless batteries are re-charged.

Receiver current consumption can be dramatically improved by using wake-up transceivers to turn on sophisticated transceivers. This wake-up transceiver methodology is also patented by TeraHop. Using this methodology, sophisticated transceivers are turned on only when needed to transfer data. The wake-up transceiver is in a dormant state until a sensor event or a request from another node wakes it up. When fully awake and ready to transfer data, the wake-up transceiver of a given node signals the wake-up transceiver of another node, and together they wake up and turn on their sophisticated transceivers, and transfer data. Once the data are transferred, the sophisticated transceivers shut down.

Such a wake-up transceiver achieves its low current drain by its simplicity (hence, calling such transceivers Reduced Complexity Radios – RCRs). Despite the simplicity, selectivity is achieved via class designations. Since the amount of data exchanged by wake-up radios is tiny, sensitivity is not an issue.

In addition to exceptionally long battery life (measured in years) that results from the use of wake-up transceivers, the conserved battery and minimal operating time of the sophisticated transceivers affords the use of higher-power sophisticated transceivers for transferring data. Consequently, the use of wake-up radios can render both long battery life and long range.

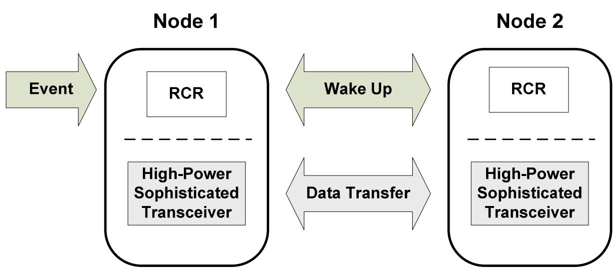

Figure 3.
Nodes with Wake-up Transceivers

E. Hopping

The wake-up-then-transfer-data process described above can be repeated from node to node, in a daisy-chain. Each node is successively awakened, then awakens others, transferring data from node to node, until the data reach the intended destination. In this way, messages and commands can be "hopped" through the network.

F. TeraHop Implementation

TeraHop's implementation of class-based networking comprises:

- Remote Sensor Nodes (RSNs), comprising a simple wake-up radio, a Class 1 (up to 100 mW) Bluetooth radio for data traffic, a controller, battery, antennas, and a suite of internal sensors. RSNs are attached to assets (people or things) that one wishes to monitor or track.

- Gateways, comprising radios to communicate with RSNs of the local network, radios to communicate with the outside world and user applications (e.g., cellular, Wi-Fi, etc.), and a controller. Networks form around at least one gateway, and gateways can be placed anywhere: permanent locations, temporary locations, or on conveyances (trucks, trains, ships, etc.). Gateways also include a GPS receiver, which enables user applications to report the location of RSNs (i.e., the assets to which they are attached) that are in communication with the gateways.

- Server application and database, which manage the routing of data to/from the local RSN network and provide an interface to user applications.

Using the A-nodes of Figures 1 and 2, these three elements are shown schematically in Figure 4.

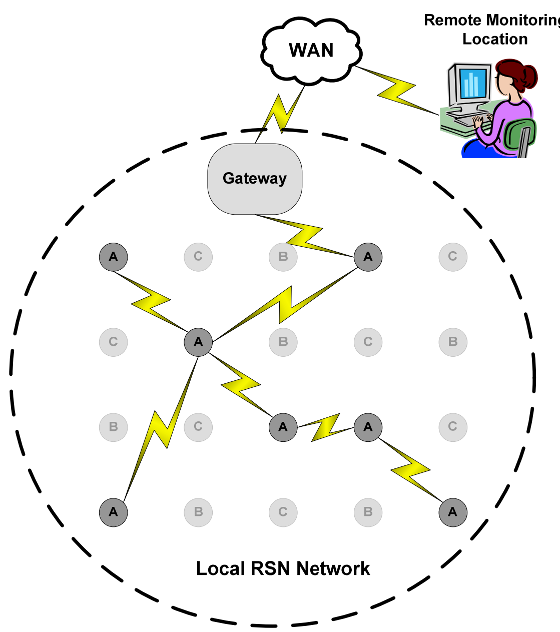

Figure 4.
TeraHop Networks Implementation of CBN

Gateways cover areas (measured in acres), and, due to RSNs' hopping capability, this coverage is extended by RSNs that are in communication with the gateways. Consequently, detecting the presence of assets/RSNs as they come and go does not require bringing those assets into close proximity (feet) of a reader, nor vice-versa, and the amount of gateway infrastructure needed to cover a given site is minimized.

Additionally, the employment of wake-up and class-based networking can yield a stealthy network. RSNs are "polite" and "talk" only when they need to, when they are requested to, or when they *initially* sense the presence of a network. Consequently, such a network puts less RF into the air (reducing the risk of interference with other networks) and can be more difficult to detect by those who do not need to know about the network.

3. Applications

The long battery life and long range that are facilitated by class-based networking and by using wake-up transceivers make true monitoring and tracking of mobile/movable assets practical. This practicality opens many applications that heretofore have not been addressable. Those applications include:

- First responders
- Shipping containers
- Construction equipment

A. First Responders

In a first-responder application, RSNs would be worn by firefighters and/or other first responders, and gateways would be mounted to trucks and engines. Responding to a fire, as firefighters get into their truck, the gateway on that truck would automatically note the presence of who is on board.

Upon the unit's (truck and firefighters) arrival at the scene, a gateway on the incident commander's vehicle would automatically note the unit's arrival, and the unit's gateway would tell the incident commander's gateway who was on board. The incident commander's gateway would send data to an application on the incident commander's laptop, to display the unit's arrival (and all subsequent arrivals of other units). A cellular link from the incident commander's gateway to dispatch could convey the GPS data of the incident and the identity of all units that were present, for graphical display.

As the incident progresses and the incident commander makes assignments using his laptop, commands would be sent to the RSNs at the scene to change classes and corresponding behavior, depending on those assignments. These changes could include having the RSNs detect the absence of motion, which could be used as an alarm that a firefighter was in distress, supplementing PASS[1] devices. At the end of the incident and as units left, the incident commander's laptop would automatically inform the incident commander that units were no longer present, supplementing other accountability measures.

As units return to their stations, gateways located there could automatically report their return to dispatch and automatically upload incident records to an archive for later analysis.

The long battery life facilitated by wake-up transceivers and class-based networking obviates having to recharge (and *remembering* to recharge) the RSNs, or even having to remember to turn them on. Rather, RSNs are always on and can even be worn off-duty. Class designations on RSNs and gateways can also help keep different services (fire, police, EMS) and different jurisdictions from becoming confused.

The RSNs' long range afforded by their high-power data radios, their hopping capability, and the capabilities of autonomous network configuration facilitate good coverage at the incident scene, as firefighters move around, including in buildings. Further, due to the area-coverage capability of the network, the presence of firefighters and their vehicles can be known without the incident commander ever laying eyes on them or having to enter data into a monitoring system manually. Special tag readers and "passports" are similarly not required.

B. Shipping Containers

In a shipping container application, an RSN would be integrated with a security bolt that would be applied as a security seal through the container door hasp. Gateways would be located at origin and destination sites, and at various intermediate locations along the shipping route (e.g., ports, rail yards, truck stops, weigh stations, etc.).

At the shipper's location, sealing the door would be automatically reported to a gateway at the shipping dock and, via a user application, associated with the shipment number. After leaving the shipper's location, the lack of presence would automatically be reported.

Arrival at port would automatically be detected and reported by gateways at the port. Even if in a stack of containers, messages from RSNs could reach a gateway (and vice-versa), due to the high-powered data radios, and due to the hopping that is facilitated by autonomous network configuration, which is enabled by class-based networking. If a container is moved when it should not (indicating theft), or if a container is jarred enough to damage contents, the event is reported immediately and automatically.

Similarly, an RSN could report dangerous excursions in a container's temperature or the presence of dangerous vapors, if connected to appropriate external sensors.

Aboard ship, the presence of the container is known to a gateway on the ship. The gateway could use a satellite link to report its (and the ship's) location and/or to respond to locating and status inquiries. Similarly, sensor inputs from each container/RSN can be known.

Once the container reached its destination, or at any location since the original sealing, every opening or closing of the seal would be recorded. If at a location covered by a gateway, the event would be reported

[1] Personal Alert Safety System

immediately. If not at a covered location, the event would be stored and reported immediately upon encountering a gateway.

In such an application, classed-based networking and wake-up technology enable more than enough battery life to complete multiple door-to-door transoceanic shipments. Battery life is so long that responsibility for the batteries rarely becomes an issue among the many entities who may handle the RSN/seal. Class-based networking also enables different shippers or different shipping companies to share the gateway infrastructure of the ports and of other shared locations without interfering with each other's traffic, yet facilitate hopping of others' messages when needed.

For example, XYZ Shipping may configure its RSNs to communicate, under normal circumstances, with only other XYZ Shipping RSNs, but to assist hopping for other companies' RSNs when needed. Under those ordinary circumstances, wake-up and data traffic from other companies' RSNs would be ignored by XYZ Shipping's RSNs. However, if ABC Shipping had a container deep in a stack, and its RSN needed a hop-assist to reach a gateway, the RSNs of XYZ Shipping could make the assist. The ABC Shipping RSN would automatically make a request for an assist if it failed to reach a gateway using only its own class of RSNs. In this manner, class-based networking facilitates handling 1000s of containers that may be at a single location.

The area-coverage capability of the network means, for example, an entire port facility may be covered. Consequently, the presence of containers/RSNs can be known at any time (queries may be made), and special detection lanes or choke points are not needed.

C. Construction Equipment

In a construction equipment application, RSNs would be attached to backhoes, dozers, cranes, etc. Gateways would be located at equipment rental yards and construction sites. A rental company could use the presence data generated by the RSN network to know in which of multiple yards specific equipment was located, real-time, to meet customer needs, real-time. Improper movement data could be used to trigger theft alarms (which could include gates and perimeter fencing, as well as rental assets).

At a renter's construction site, a gateway there could receive engine-hours data from RSNs on equipment at that site and report back to the rental company. The rental company could use those data to determine whether the renter was exceeding his contract and/or whether the equipment were being abused. If the site had no gateway, the rental company could use a truck-mounted gateway to periodically visit all sites to collect data from the RSNs there. The data would be collected quickly and automatically, and could be immediately uploaded via cellular link to rental company headquarters.

A construction company could similarly use the system to keep track of and monitor its own equipment, both in storage yards and on construction sites. For those construction sites that had both rental and owned equipment, classes could be set such that the rental company could "see" its equipment via the site's gateway, but see nothing of the equipment owned by the construction company.

D. Other Applications

Many other applications are possible. In general, appropriate applications have assets with these characteristics:

- High-utility, high-value assets, that
- Change operational location, and that are
- Bigger than a breadbox, but smaller than a house, and that
- Are not powered for long periods or at all, and that
- Dwell temporarily, and/or that
- Are remotely located or spend long periods unattended

These assets may be:

- In regular use
- Stored
- Pre-positioned/configured for emergency use

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For more information, please consult the author Joe Denny by writing to: jdenny@terahop.com

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References

Twitchell, Robert W., Jr., and Smith, Delia J., *Class-Based Networking: A Novel Approach to Asset Tracking and Sensor Monitoring*.

Twitchell, Robert, Jr., *Battery Powered Wireless Transceiver Having LPRF Component and Second Wake Up Receiver,* US Patent 7,209,771.

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