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CCS: A RAILWAY CORRIDOR CONTROL SYSTEM UTILIZING ULTRA WIDEBAND RADIO TECHNOLOGY

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ABSTRACT

Ultra Wide Band (UWB) radio is a unique technology which combines a megabit wireless local area network with a centimeter-resolution radiolocation (RADAR) capability over distances less than 100 meters. A linear chain of UWB nodes can be used to create a hop-by-hop data transmission network, which also forms a RADAR "corridor" along the chain. By co-locating such a chain of nodes along a railroad right-of-way, precise information on the location and velocity of trains could be distributed throughout the corridor. In addition, the radar corridor would detect the introduction of track obstacles such as rocks, people, and automobiles, as well as shifted loads and other high-wide train defects. Finally, the network of nodes would enable off-train communications with payload sensors, locomotive computers, and could also provide wireless connectivity for passenger service.

Keywords: UWB ATCS Railroad Railway Signal

CORRIDOR PROTECTION ISSUES

Protecting the space above and surrounding the right-of-way is of concern to operators of railroads. As trains traverse a fixed path and are unable to change course, obstacle avoidance is limited to stopping the train before a collision occurs. In addition, economies of scale require the operation of multiple trains on the same rails, and often in opposite directions. Such operation has evolved over a century of experience ***[1]*** and methods into a complex system of rules for rights of track occupancy, which unfortunately, do not entirely prevent the occurrence of collisions.

Corridor Protection is seen as a central issue and impediment to high speed railway systems. Traditional protection systems often rely on time or space protection, methods which become either impractical or inefficient as velocity increases. Unfortunately, the consequences of a protection failure are compounded as well, as the energy of collision rises with the square of velocity.

A number of methods have been used historically to preserve the integrity of the right-of-way corridor space; these may be grouped as follows:

- *Positive Corridor Assurance Methods*: These approaches attempt to physically limit access of foreign objects to the right-of-way. Grade Separation, Derailing Devices, and Tunnels are typical examples.
- *Obstacle Detection Methods*: Rather than prevent access, these techniques focus instead on detection and warning. Slide Fences, Defect Detectors, and Block Signals are examples of this class.

Historically, Detection Methods have been preferred, as their capital costs are substantially below those required for Positive Assurance. Total grade separation has been utilized on some lines, but in spite of the expense, foreign objects have entered the right-of-way corridor. In addition, Positive Assurance techniques do not address the need for multiple use of the corridor. As a consequence, most Positive Assurance installations also deploy Detection Methods, both as a backup and to allow for multiple use. The optimum is thus seen as a

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combination of the two approaches – limit access to the right-of-way, detect intrusions which are not prevented, detect impending collisions, and communicate this information to prevent collisions.

DETECTION AND COMMUNICATIONS

A variety of methods have been used to detect the introduction of foreign objects, including rocks, mudslides, and avalanches. Electrified Slide Fences are often used in such cases. The wires of the fence constitute an electrical circuit; each wire is plugged into a fencepost at either end. The mechanical action of intrusion upon a fence wire causes the plug to be dislodged, thereby breaking the circuit. Other techniques include the use of light beams and photodetectors (typically used for shifted load detection), seismometers, netting with strain gauges, and so on.

Usually these techniques require some foresight for deployment, or are installed as the consequence of a prior collision. Owing to their expense of installation and maintenance, they are not generally employed throughout a rail corridor. In addition, the high rate of "false positives" generally decreases the efficiency of the corridor, and may lead to collision accidents from ignorance.

Recently, attention has been focused on the detection of trains within the corridor. The traditional method of detection is the Track Circuit, where the two rails form an electrical path when connected by the wheels and axles of a train. Direct Current Track Circuits, which are subject to noise from track oxidation and induction, are gradually giving way to radio frequency systems, which are more immune to noise, and can provide range and velocity through time domain reflectometry. Experiments with Satellite Geolocation have had mixed results ***[2]***, owing to difficulty of satellite reception in deep river canyons which are often the preferred geographic routes for rights-of-way. In addition, the precision available from satellite geolocation is unable to determine individual track use on multiple track lines. Localization techniques have been suggested to remove the ambiguity, however, these require expense of deployment and maintenance, and only provide information in their immediate vicinity.

A variety of communications methods may be used to transmit information from the deployed corridor detectors to railway operators. The traditional method transmits a detected indication through a wired circuit, which changes an optical signal aspect. Fixed signals along the corridor convey this information to the operator of the train, who is expected to take appropriate action. In other systems, the information is conveyed to cab signals, or directly to braking controls, through the use of inductive pick-up shoes mounted on the controlling locomotive. Radio data or SCADA systems have also been used, although their range limits their application. Recently, mobile satellite communications systems have also been tested ***[3]***, again with mixed results owing to terrain. All of these techniques share a common characteristic of low bandwidth, ranging from 1-56,000 bits per second, which limits the amount of information that may be conveyed from detector to operator.

Thus it can be seen that a satisfactory solution to the detection problem presently requires a great deal of foresight and expense. Existing systems provide a solution to intrusions and operations which can be anticipated. However, railway collisions are often the consequence of unanticipated events. Furthermore, the fixed anticipatory methods of detection and communications make railway operation particularly vulnerable to sabotage and acts of terrorism, a vulnerability which is further multiplied when the corridor is operated at high speed.

ULTRA WIDEBAND RADIO TECHNOLOGY

Recent, rapid advances in low-cost precision timing devices have led to the development of Ultra Wideband ***[4,9]*** wireless local area networks. UWB is essentially a form of pulse-position modulation, utilizing nanosecond pulses. Picosecond-precise time coherence between receiver and transmitter provides noise rejection characteristics akin to filtering in conventional frequency-domain based communications systems, but far superior in practice. Research UWB network nodes ***[5]*** have a range of 100 meters, carrying a 100 megabit-per-second channel with 10^{-6} bit error rate, while requiring only 10mW of power, 30db less power than conventional narrowband techniques.

Another advantage of UWB's time-domain approach lies in the elimination of multipath interference**.** Reflected waves arrive with some delay, depending on the distance of the reflector from the transmitter and receiver, resulting in Rayleigh distributed fading in the frequency domain ***[6]***. Thus, conventional networks must either employ higher power levels to overcome the fades, or apply multiple receivers to provide diversity. In contrast, the time-domain receiver simply rejects the reflected pulses out of hand, as they do not arrive during the receiving window.

Rather than ignore the reflected pulses entirely, a receiver may instead simply record the timing of the reflection relative to the primary signal, as well as relative signal strength and phase. Through such a record, a receiver can determine range and relative velocity of reflectors within the immediate area. Thus a UWB receiver produces a simple radiolocation map – RADAR –as a byproduct of operation. Practical UWB radiolocation presently has a precision of ten centimeters, with a theoretical sub-centimeter limit. Research systems have applied adaptive array antennas, which are capable of providing azimuth and elevation data in addition to range ***[4]***.

ULTRA WIDEBAND CORRIDORS

A chain of Ultra Wideband nodes, deployed co-linearly with a railway right-of-way, would enable the detection of foreign objects, locate and track opposing trains, while at the same time providing a high bandwidth data conduit for elements within the corridor. In practice, UWB nodes would be placed on poles or existing structures such as cantenary supports, spaced for duplex redundancy, as shown in Figure 1. As power requirements for the nodes are modest, passive power techniques – induction from cantenary, photovoltaic cells, or methanol-based fuel cells ***[10]*** – will suffice.

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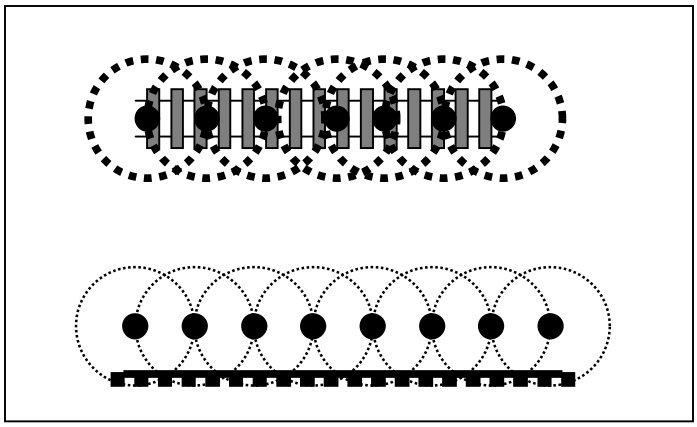

Figure 1: Ultra Wideband / Railway Corridor

In operation, UWB nodes keep track of both static and dynamic reflectors in the corridor. Once the right-of-way is clear of obstructions, the network need only detect *intruding* reflectors, as these are logically capable of colliding with trains. The UWB nodes form a kind of linear mesh network, with data routed up and down the chain of nodes. As each hop in the network corresponds to a set distance, packets of information may also be broadcast along the network over a pre-defined distance. Thus, information about intruding reflectors may be broadcast along a preset distance through the corridor.

One useful addition to the UWB node would be a wide angle digital imager. Digital imagers have been utilized for remote obstacle detection, by comparing pixels between frames ***[11]***. However, these "Optical RADAR" techniques often produce false detections, owning to the absence of depth information as well as optical effects such as moving shadows. Combining the data from the imager with the ranging information from the UWB receiver would correct for these defects, and provide the missing azimuth and elevation location in a cost-effective manner. In addition, images of intruding reflector may be transmitted along the corridor network to equipment operators.

Mobile UWB nodes may be placed on railway equipment, both to communicate with the corridor, and to identify a particular reflective object. A locomotive can thus be located by its reflection, identified by its UWB node, and the communication itself between the corridor and mobile node provides a redundant method of location within the corridor. This also allows, for example, the detection of parted trains, as well as stolen or sabotaged run-away trains.

Mobile UWB nodes can also be used to communicate information regarding locomotive and cargo status, as well as wayside equipment such as infrared hotbox detectors. They would enable, for example, remote control of refrigeration units on cargo containers, tampering with container locks, shifted loads, recording of coupler slack forces, and so on. Relevant information regarding the corridor would be conveyed to the operator of the train, as well as enabling the operator to remotely control track switches.

Additionally, the data from the corridor may be downlinked from the network of UWB nodes to other networks, allowing the data to be shared with a remote location such as dispatching office. In turn, commands from the dispatching office may be uplinked to the network, to provide for control of remote devices.

UWB AND THE ADVANCED TRAFFIC CONTROL SYSTEM (ATCS)

The Advanced Traffic Control System provides architecture, protocols, and other standards for networks of detectors, track switches, locomotives, and other objects along the right-of-way. Figure 2 depicts the overall ATCS architecture as documented in AAR Specification 100***[7]***. In practice, the Communications Network is implemented as depicted in Figure 3. Localized nodes communicate via the Mobile Communications Package, a VHF radio data link described in Specification 200 ***[8]***. In turn, these localized networks are often connected back to a centralized dispatch office through point-to-point carrier links.

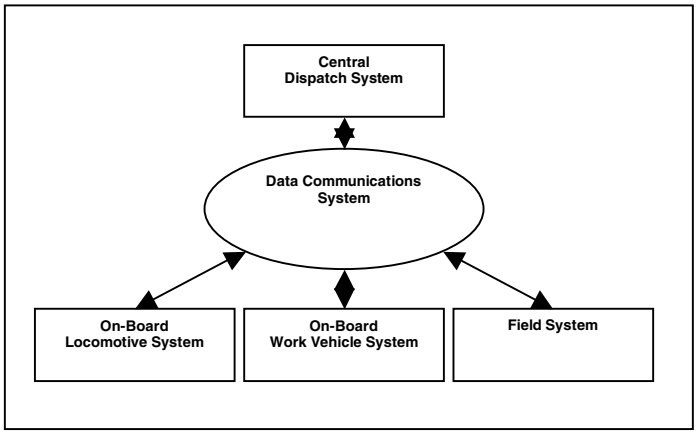

Figure 2: ATCS System Architecture

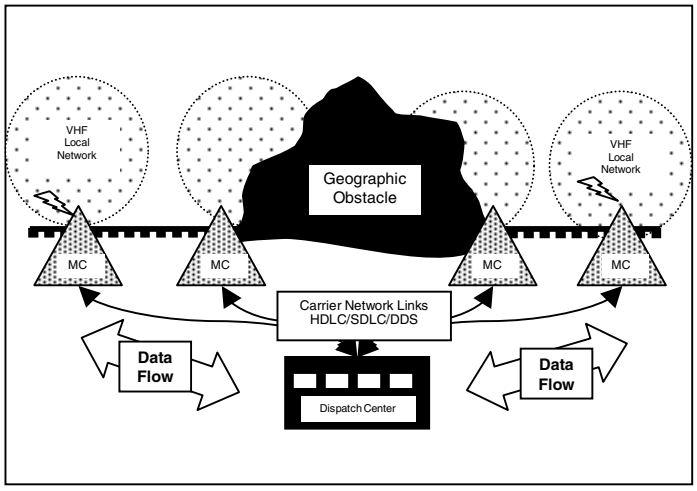

Figure 3: Typical ATCS Network

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A linear network of Ultra Wideband nodes provides identical functionality to the VHF radio data link portion of the MCP, and would provide significantly improved communications capability, as illustrated in Figure 4. The UWB network effectively covers an entire railway line, instead of pre-specified locales. It would eliminate the need for wireline links between locales, and require only a pair of redundant carrier links to the dispatching center. UWB performs far better in a multipath radio environment, having virtual immunity from fading which is prevalent in narrowband VHF data systems. In addition, the available bandwidth, in hundreds of megabits, dwarfs that of narrowband radio (tens of kilobits). Finally, UWB security is inherently better, owing to the difficulty of uncooperative synchronization and localization of signal. Thus, an addendum to Specification 200 which incorporates a linear Ultra Wideband network would enable the use of existing and future ATCS protocols directly.

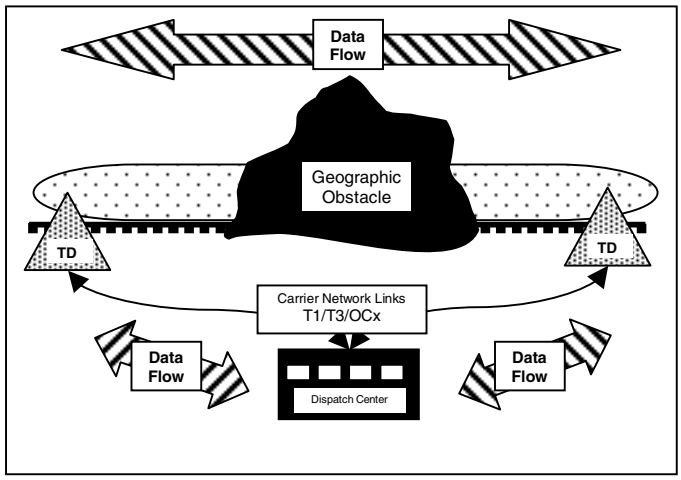

Figure 4: UWB-Based ATCS Network

The RADAR functionality of the UWB nodes would require their inclusion as additional Specification 200 devices. However, the practical integration of such devices into ATCS will require additional protocols and systems, in order to fully benefit from the information gathered. For example, an automated dispatching system must include the capability to combine data from multiple nodes in order to determine a collision is imminent, and must contain additional logic to determine the appropriate course of action (inform the operator, shut down locomotive power, apply brakes, etc.).

Beyond ATCS compatibility, however, the UWB network completely distributes data within the corridor. Unlike the existing ATCS architecture, this would enable the use of distributed control, which would significantly enhance the reliability and performance of the system. Under the existing ATCS architecture, train location is determined by signal block, then passed to the Central Dispatching System. When the Dispatching System determines an opposing movement, it then changes wayside signal aspects to prohibit a collision. The UWB Corridor Control System provides equivalent functionality; however, location is determined much more precisely, velocity is detected, and a signal aspect delivered to a locomotive cab signal anywhere within the corridor. Moreover, the redundant detection of an opposing movement may be done on board the locomotives themselves to enable precise, reflexive braking action. Finally, the Corridor Control System enables dynamic blocking of trains, eliminating the need for fixed signaling blocks altogether, and improving corridor capacity. The CCS thus accomplishes goals beyond those of Positive Train Control ***[2,3]*** in a cost-effective manner.

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