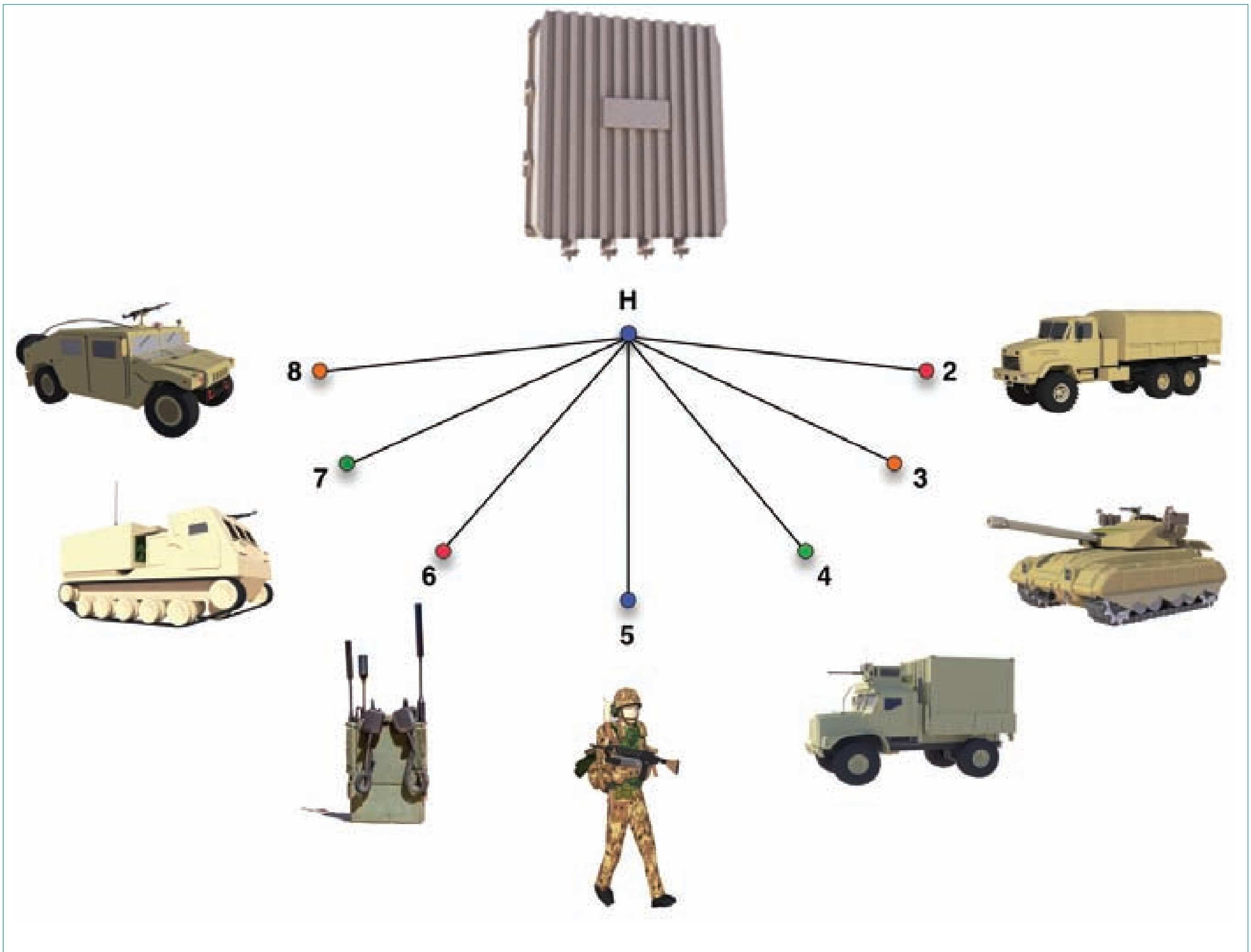

Figure 1. Hub network

Multi-hop wireless mesh networks for V2V/M2M: Network testing challenges and solutions

Manufacturers and designers of vehicle-to-vehicle (VTV) communications equipment and networks can face significant 'lab logistics' challenges in testing and validating RF signals for mesh network topologies. David K. Chan, Vice President of Sales & Marketing for Quintech Electronics, Inc, discusses test lab challenges and how test engineers have found they can achieve dramatically reduced test schedules and increased accuracy in RF link testing for mesh networks. The key to achieving these results has been the use of new advanced RF matrix switch test and measurement systems.

In military operations, when convoys, command centers, UVs, supplies, soldiers and vehicles are brought to an area where there are no reliable communications infrastructure, mesh networks can allow for these distributed assets to connect to each other via voice, video and data without the constraints associated with traditional wired and shortwave radio networks. Mesh networks offer advantages for military vehicle-to-vehicle field communications. They provide flexibility for establishing and maintaining reliable communications, even when network nodes are partially lost due to terrain or weather or if frequencies are being jammed. However, the ability of mesh networks to rapidly adapt, self-heal, and meet on-the-move and other requirements also creates challenges in testing, validating and verifying network resiliency.

Terrestrial wireless mesh network connectivity requirements have been part of the military communications landscape since line-of-sight radios and hub and spoke networks could no longer meet the reliable communications requirements needed for today's modern warfare. For example, the US Marine Air Ground Task Force has been using mesh networks for the Networking on the Move (NOTM) command and control capabilities since 2009.

A number of new requirements are increasing the rate of demand for wireless mesh networks in military communications. The evolution of military field communications has grown to include live video, voice and data over wireless digital data networks that require very large uplink and downlink bandwidths. Over-the-air (OTA) networks for field personnel are typically mission critical and require over 99.999 percent resiliency in a mobile environment. The network needs to be flexible to allow

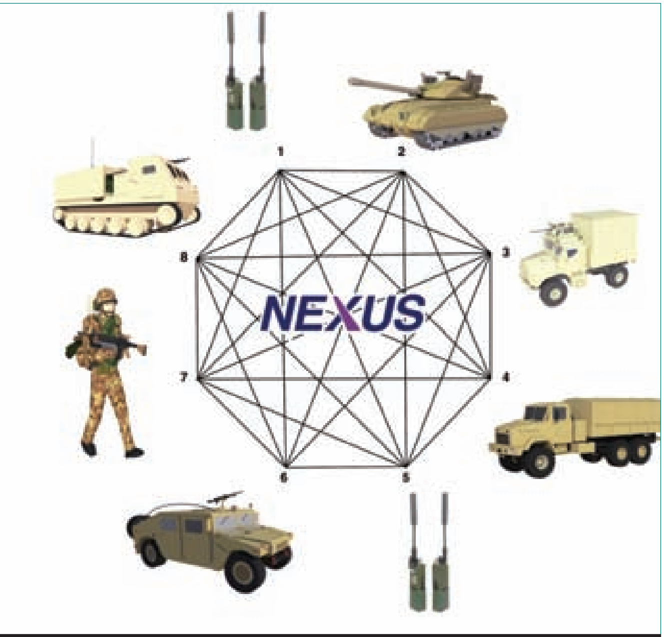

Figure 2. Full mesh network

nodes to maintain connectivity as they change distance with respect to each other and as the terrain changes and interferes with the line-of-sight. A mobile wireless mesh network can be established where no infrastructure exists and enable mobile assets to seamlessly leave and join the network. Multi-hop wireless mesh networks that are mobile, ad-hoc, self-forming and self-healing can support a full range of situational awareness data.

Hub-based networks

Basic hub (also known as Star) networks rely upon a central server and substations to manage traffic between nodes (Figure 1). This network configuration contains single points of failure that then requires redundancy designs to maintain network connectivity. For some field applications, the resiliency requirements will dictate redundancies that are very costly. The hub and number of substations need to be planned in advance to accommodate the changing configuration of the network where the number and distance between the nodes and hub and substations will change. If there are not enough substations built into the network, there is a risk that the nodes will lose connectivity.

Mesh networks

A mesh network integrates a subset of server capabilities into each node, so that each node in a full mesh network can have a point-to-point connection with another node, and also each node can pass the data packet along to the next node. As there are multiple paths available to make a point-to-point connection, a mesh network will always be able to make and maintain a connection, even with the loss of a node. Figure 2 shows an 8-port full mesh network where each node can have 7 direct connections.

In a real life wireless mesh network, a full mesh network is dependent upon the distance between nodes. As the distance between nodes increases or the line of sight is lost, the connection between nodes will be lost. Figure 3 shows an example of a partial mesh network where nodes have a limited number of nearest neighbour connections due to signal level connectivity. As the nodes move relative to each other, the network connections will change depending on detected signal strength. Nodes that move away from each other will have decreased signal level until connectivity can no longer be maintained. Nodes that move toward each other will have increased signal level to a point where a connection is made. The mesh network can accommodate these changes.

The ‘server intelligence’ built into each node is limited in comparison to a full server. In a partial mesh network, a node can have a connection with a node that is not its nearest neighbour by having its nearest neighbour pass the packet along to its next nearest neighbour and so on until the packet reaches its intended node. Depending upon the intelligence of the server, it can route the packet along the shortest path, or, it can be routed along a ‘random walk’ path until it reaches its intended node. The number of different paths will affect the time (latency) for the packet to reach its intended node. For many networks, the latency can be critical to the speed of the network.

Time division multiple access (TDMA) networks share the same frequency channel by assigning different time slots to send packets between network nodes. In a military radio application, a TDMA network might also use multiple channels to transport signals, e.g. a 40Gbps bandwidth can consist of four channels of 10Gbps signals, providing a throughput total of 40Gbps. The packets that are transmitted are expected to arrive within a predefined tolerance (which is dependent upon bandwidth) of each other. If there is too much delay between packets, an error occurs and the system is required to ask for the packets to be resent. The latency tolerance can be increased using forward error correction (FEC). A hub network relies on the substations to route the packets toward the intended target. The substations can be subject to delays due to heavy packet traffic, which can increase the transmission latency. A mesh network minimizes latency with a one hop connection when available. Packet routing in a mesh network has additional complications as nodes can be added or dropped at any time.

Due to spatial and line-of-sight constraints, the mesh network is most likely a partial mesh configuration, where each node has a limited number of nearest neighbours. The number of nearest neighbours can change over time as the nodes move with respect to each other. Dynamic configuration presents many challenges for packet routing, and TDMA networks need to be able to adjust to the changing number of nodes, number of nearest neighbors, etc. To ensure that the network meets the resiliency requirements, it is imperative that the firmware is able

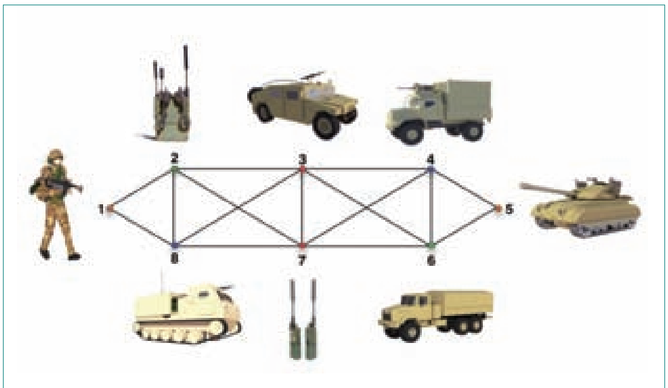

Figure 3. Partial Mesh network, nodes have limited nearest neighbor connections

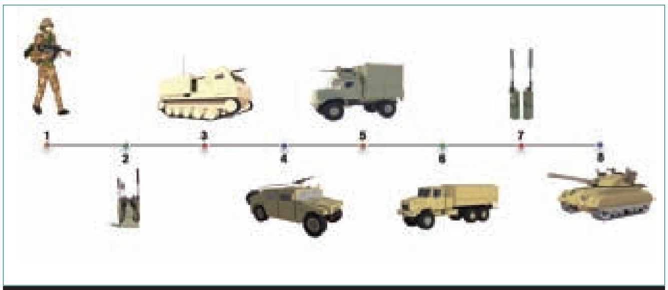

Figure 4. String network

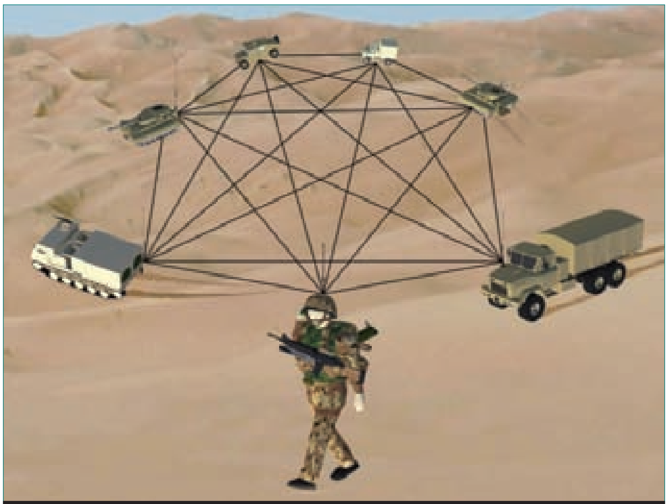

Figure 5. Mesh Networks that can be rapidly simulated using the Quintech NEXUS matrix switch a) Full Mesh

to adapt to the constantly changing network configuration as well as have the intelligence to recalculate the shortest path. Firmware needs to be tested and verified on a network where the number of nodes, the distance between nodes and the nearest neighbour connectivity are changing. A simple base line test configuration of packet hopping through multiple nodes would be a string configuration (Figure 4).

Testing mesh RF signals

The time and cost to demonstrate a live system can be very high, and successful lab verification of the mesh network is critical prior a live demonstration. Emulation of terrestrial RF wireless signals in a test bed requires shielding of the signals from outside commercial signals and other sources of electromagnetic interference by transporting the RF signals over coaxial cable. A mesh test system requires the use of a splitter at every device node that is interconnected to all the other nodes. An attenuator at each node is needed to vary the signal strength. It is long and tedious to manually change cable connections between nodes and vary the signal levels. An RF mesh test matrix, such as Quintech's NEXUS brand of Test & Measurement switches, allows node-to-node Layer 1 connectivity that emulates connections of the RF signals between nodes. The NEXUS matrix switches integrate the splitters, attenuators and switches into a remotely controlled chassis. Figure 5 shows real world scenarios of a) full mesh, b) partial mesh and c) string networks that are rapidly configured using the NEXUS mesh matrix switch.

The NEXUS provides any node to any node connections and allows distance between nodes to be emulated using variable attenuators to adjust the signal levels. The Quintech NEXUS matrix is an industry proven non-blocking RF matrix switch that can connect any A port to any B port with independent 0-60 dB variable attenuation per connection. The addition of a splitter array enables any node to any node connectivity to fully implement the mesh network topology. The NEXUS mesh matrix is an inherently modular design that provides excellent scalability and can be configured to support 8, 16, 32, 64 and 128 nodes. Link parameters such as link path loss and connectivity (on/off) for any node to node can be changed in milliseconds.

Test engineers are able to emulate joining, leaving, grouping and splitting of mesh networks using the NEXUS' mesh matrix ability to provide real time switching and attenuation of all the radio links individually. A test engineer or team can use the NEXUS mesh matrix to develop, analyze and verify the upper layer protocols in multiple realistic configurations and test the mesh network's resilience under dynamic configurations.

In one successful example of the use by the US armed forces, a provider of fighter aircraft avionics and navigation radio systems and vehicle mount military radios needed to validate and certify their new product for compliance with Joint Tactical Radio Systems (JTRS) Software Communications Architecture, and "to leverage its expertise in more than 50 waveforms and functions used on advanced networks and platforms" to create a battlefield communications radio for the US military.

The system needed to support on-the-move communications using a broad range of RF communications technology and missions. By using Quintech's mesh matrix testing solution, the hardware supplier could rapidly test the mission's baseline waveforms, such as WNW, SR, cross-banding and channel bandings, as well as future waveforms such as SINCGARS, V/U LOS, UHF SATCOM, and MOUS.

Performance testing of packet loss, latency and throughput can be measured much more efficiently and accurately with this automated solution compared with manually changing patch panels between test measurements. By using these kinds of test solutions, engineers have been able to test *many more* configurations in much fewer lab days and hours, with cases of *four-fold productivity gains*. The ability to efficiently validate and test complex RF link scenarios can be expected to remain an important requirement for equipment and network builders as they address evolving market demands for vehicle-to-vehicle radio equipment and networks. **GMC**

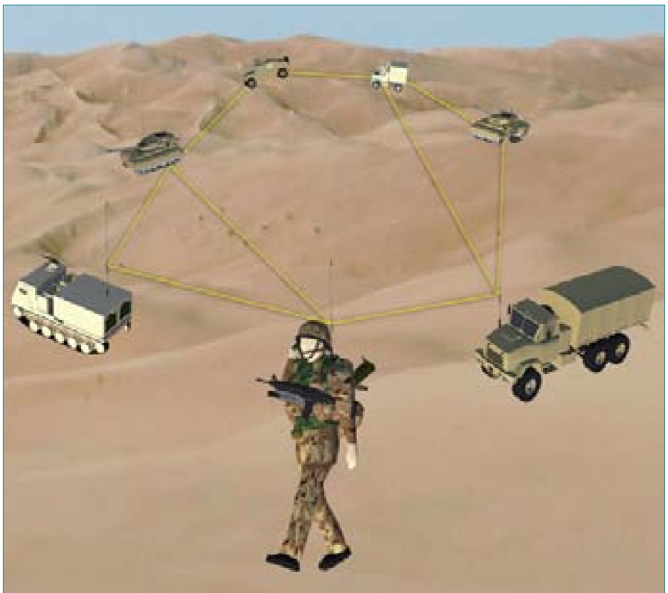

Figure 5 b). Partial Mesh

Figure 5 c). String