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The Super Het Mesh Net

In this month's technology we review radio systems where devices talk to each other directly rather than via a network node/base station. They are variously described as autonomous radio networks or in emergency response radio systems as direct mode or back to back working.

They are essentially radio architectures where a user or IOT device can work out its own communication route via adjacent devices. Provided all devices are within range of each other it is theoretically possible to scale these networks to cover large geographic areas, a wide area mesh net.

TETRA is an example of a wide area VHF and UHF wide area network technology that can work in direct node with user devices either functioning as repeaters, relays or gateways. This can include airborne radios flying or hovering over emergency response situations.

As a reminder, the difference between a repeater and a relay is that **a repeater receives** a signal, **amplifies** the signal **and retransmits** the signal. In the satellite world this is known as a bent pipe.

A relay takes a signal, **demodulates** the signal to recover and clean up the baseband signal, **remodulates** the signal, **amplifies** the remodulated signal **and** then **retransmits** the signal, usually at another frequency to avoid interference between the incoming and outgoing signal. In the satellite world these are known as regenerative transceivers.

A repeater will amplify noise and will therefore not always realise range gain if used in marginal signal strength conditions. A relay improves the signal to noise ratio and carrier to interference and therefore increases range and can improve performance in interference limited environments but introduces processing delay and additional clock processing overheads.

A gateway provides a bridge between relays and repeaters and core network connectivity.

The TETRA terrestrial radio interface, as with most digital radio systems, has a time frame slot structure which allows devices to discover adjacent devices and to signal and communicate with those devices.

The Direct Mode specification covers back to back working either as a repeater or relay with the repeater operating either on a single frequency or dual frequency.

Any single device can also operate as a gateway to a trunked radio network. A dual watch radio is a combination of both modes with the ability to communicate via a gateway or back to back in repeater or relay mode.

The operational benefits include extended coverage either underground or over ground, for example for an underground rescue operation where there are no existing installed radio links or above ground where masts and base stations may have been destroyed. Direct mode can also be used for localised site coverage, for example an open cast mine where coverage into external networks is not required. Mesh based radio systems are also available in the sub 1 GHz ISM bands.

Many local area and personal area networks standards including Bluetooth and Wi-Fi support direct mode operation, often described as a piconet and/or ad hoc network.

Standard (Classic) Bluetooth devices are an example of an ad hoc piconet where a master device controls up to seven slaves per piconet, the slaves communicate with the master device but not each other but a slave can participate in more than one piconet. These multiple piconets are described as scatternets.

These protocols require regular listening and response are therefore modified for devices where low power consumption is critical. This is documented in the 4.0 and 5.00 Bluetooth Low Energy (BLE) specifications and essentially makes the master device responsible for minimizing polling overhead.The protocols support power idle mode operation, fast device discovery, and point-to-multipoint data transfers.

The Wi-Fi direct protocol covers similar territory specifying peer top peer ad hoc networking, automated device discovery and inter device capability awareness, power management and infrastructure-less connectivity with the devices acting as autonomous access points. Devices can also operate in simultaneous mode supporting P2P and internetwork communication, effectively equivalent to the TETRA dual watch radio protocol.

Cellular networks could theoretically support direct mode operation as a commercial service offer. The LTE standards from Release 10 have supported relay and repeater modes to support the implementation of air to ground LTE for major event coverage and public protection and disaster relief (PPDR) operation.

The definition of an LTE relay is a device that receives, demodulates and decodes data, applies error coding and the retransmits to a user or IOT device or another relay. This is effectively infrastructure without a wired connection.

The relays can either operate as half duplex where communication is supported in both directions but not at the same time or full duplex where time slots are allowed to overlap with the later requiring some careful RF planning not always consistent with ad hoc network deployment. There is no point in flooding an area with relays to provide instantaneous additional capacity gains if all they do is raise the interference floor.

Counter intuitively it can be easier to manage ad hoc additions to a network where the devices operate in band rather than in adjacent channels. This has led to subsequent study work on the use of in band relays and repeaters to provide in band backhaul, front haul and cross haul for 5G urban connectivity, addressed in detail from Release 15 onwards.

The use of relays and repeaters that remain under the control of the network operator is a perfectly comfortable concept. The use of repeaters and relays in an autonomous or partially autonomous network particularly when scaled to wide area radio is not so simple either commercially or technically.

Commercially there is an issue of how to bill for a service that could theoretically be interdependent of the network. Provided user devices are within range of each there is no technical reason why any of the end to end routing should go through the core network but that implies that the network has no visibility to the traffic exchange and no control over the interference that could potentially be generated by the devices operating in ad hoc mode.

There are ways round this, for example devices only search for other direct to device links when there is no available network service and the billing event is captured and uploaded to the network when connectivity is re-established. The alternative connection model is when devices are connected via other devices to a Node B. Here the problem is not a billing issue but a user

experience issue as effectively you have used someone else's battery power to get you connected to the network.

The answer may be to move the problem upwards.

Whenever a device cannot see a terrestrial network node it should look for a node directly upwards which will either be an air borne platform or LEO, MEO or GSO satellite.

Within the 3GPP standards process this is being addressed by the 3GPP TR 38.811 work group which to date has been studying air to ground and space to ground connectivity propagation models but arguably could now pursue a broader brief.

With the exception of underground and deep in building coverage, satellites have always been able to reach the parts that terrestrial networks cannot reach, oceans and deserts and mountains but to date these systems have been separate from cellular.

Bringing satellite in band into LTE and 5G cellular radio spectrum between 400 MHz and 3.5 GHz and into sub GHz private radio spectrum at VHF and UHF would make these terrestrial systems fully global unlocking geographic user value which is either impossible to address using terrestrial networks or uneconomic to address using terrestrial networks.

Satellite also have an economic advantage for mobile, progressive point to point, fixed access and in band front haul, backhaul and cross haul in many urban environments and will be particularly critical for delivering cost economic 5G smart city and automotive service offers.

The addition of a satellite physical layer could therefore scale a terrestrial mesh net to provide a personal, local area, wide area and global connectivity – a Super Het Mesh Net.

New Book - 5G and Satellite Spectrum, Standards and Scale

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