R5000 series – MINT & Mobility

Whitepaper

Software Version: MINTv1.90.23

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About This Document

This document provides technical information about proprietary MINT protocol highlighting its benefits for mobility projects with Infinet Wireless equipment.

The document is divided into four chapters:

- Chapter 1 – “Getting started” introduce abbreviations and whole document structure
- Chapter 2 – “Introduction to MINT” focus on operation of MINT protocol and its features. Since MINT is the proprietary protocol, in this chapter we focus even on step-by-step operation of the data transfer between units via MINT protocol
- Chapter 3 – “Antennas” has the main aim to provide theoretical background to proper antennas planning, positioning and operation for mobility projects
- Chapter 4 – “Examples” has configuration part explained. Moreover, here various examples of mobility projects are described in details.

It is recommended to read document consequently without jumping between chapters.

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Getting Started

Chapter 1

1.1. Document structure

This document consists of the following chapters:

- Getting started
- Introduction to MINT
- Antennas
- Examples
- Conclusion and Links

1.2. Abbreviations

The following abbreviations are used in this document:

- BATS - Broadband Antenna Tracking Solutions
- BPDU – Bridge Protocol Data Unit
- BS – Base Station
- CLI – Command Line Interface
- CN – Customer Network
- CPE – Subscriber unit, mounted at customer location (Customer Premises Equipment)
- GS – Generic Switch
- InfiMUX – Switch with MINT protocol
- IW – InfiNet Wireless
- LAG – Link Aggregation Group
- LoS – Line-of-Sight
- MIMO - Multiple-Input and Multiple-Output
- MINT - Mesh Interconnection Networking Technology
- MINT area – network from MINT units interconnected by MINT protocol as one and only transport protocol
- MINT RCMD – MINT Remote Command Execution
- MISO - Multiple-Input and Single-Output
- MVC – Mobile Vehicle CPE

- NLoS – Non Line-of-Sight
- NrLoS – Near Line-of-Sight
- OSPF – Open Shortest Path First
- PLC - Programmable Logic Controller
- PRF – Pseudo Radio Interface
- PtMP – Point to Multipoint
- PtP – Point-to-Point
- QoS – Quality of Service
- SNR – Signal-to-Noise Ratio
- STP – Spanning Tree Protocol
- STP BPDU – Spanning Tree Protocol Bridge Protocol Data Unit
- SVI – Switch Virtual Interface
- TAP – Network TAP
- TDD – Time Division Duplex
- TDMA – Time Division Multiplexing Access
- TUN – Network TUNnel
- VLAN – Virtual Local Area Network

1.3. Document marks

CAUTION

All caution warnings are marked with a special warning sign. One should pay a great deal of attention to what is written in the Caution section.

NOTE

All notes are marked with a special note sign. Notes usually contain useful comments or hints to the described section of the document.

Introduction to MINT

Chapter 2

2.1. Introduction to mobility projects

Infinet Wireless is one of the leading manufacturers of Broadband Wireless Access equipment mostly for carrier grade fixed installations. The majority of wireless installations using Infinet equipment are fixed ones, however the technology supported by Infinet Wireless was designed with mobility in mind.

This document shows how mobility projects can be implemented using Infinet Wireless (IW later on) units and technology.

Mesh networks are used very frequently in mobility projects. Mesh network topology is a decentralized design, in which each node on the network connects to at least two other nodes.

MINT protocol - Mesh Interconnection Network Technology. Proprietary transport protocol developed in IW. All IW units use only MINT protocol as transport.

Main purpose of MINT protocol is to select best path among the redundant paths and deliver data with minimal time trip through wireless (and sometimes wired) network.

Mesh-like networks can be created using units equipped with single radio module. Infrastructure interconnection (resemble mesh networking), which can be created from Infinet Wireless units with proprietary MINT protocol provide self-maintained, redundant and reliable network with load-sharing available.

Main advantages of MINT protocol and IW mesh-like infrastructure interconnection:

- **Failover** – within Infrastructure MINT MESH units automatically select better link or even reconnects in case of link quality degradation
- **Load balancing** – possibility to load multiple redundant links simultaneously
- **Mobility –** MINT units (within coverage zone of Infrastructure MESH) can reconnect to different BS while in motion. Moreover, mobile units can have multiple MINT units in order to achieve no traffic loss reconnection between different BS
- **L2 management –** MINT protocol is capable to send and execute any command on Layer 2 to any remote MINT unit connected within MINT area (all interconnections are served by MINT protocol).

This document describes how IW proprietary MINT protocol works, its benefits and drawbacks, and how features of IW MINT protocol helps to implement nomadic and mobility projects. Reports of real projects are listed as examples and success stories.

2.2. Introduction to MINT protocol

MINT main purpose is to provide path selection with best quality for wireless (and wired) traffic on Layer 2 (switched traffic).

2.2.1. MINT highlights

Path quality check

MINT constantly checks transmission quality for each link. In case of link degradation MINT quickly changes some parameters in order to keep packet loss value as low as possible automatically. In case of redundant links available, MINT will switch main traffic flow path to link with better transmission quality.

Predictive model

MINT supports predictive model to switch in advance to best path, in order to deliver data the quickest possible.

Redundancy and load balancing

MINT protocol was designed to work with multiple redundant paths. Moreover, such redundancy can be expanded to load-balancing to utilize all available connections from one customer point to another.

Minimum time for data delivery

MINT main criteria for optimal path selection is time (minimal packet delivery time).

MINT connections via wired Ethernet (MINT-over-Ethernet)

MINT-over-Ethernet is unique feature of IW, allows to select best path through network including wired interfaces. Thus, both wireless and wired interfaces would be utilized. MINT-over-Ethernet can be enabled to provide backup and redundant paths, especially for mobility projects. Pseudo Radio Interface (PRF) are virtual interfaces created on base of Ethernet interfaces provides MINT-over-Ethernet.

Switching loop prevention

MINT has built-in mechanism to prevent data from looping within MINT network (of course, take place only when redundant paths are present).

2.2.2. MINT position

MINT link is the link between two units, which use MINT as transport protocol between each other.

MINT encapsulated and transport through MINT link (or links) all traffic and all protocols. Thus, MINT is the only one transport protocol for IW R5000 family products.

MINT operates between Data Link and Network Layers of the OSI Model. Therefore MINT is capable to encapsulate and carry through link traffic of Layer 2 (Ethernet switched data) and traffic of Layer 3 (IP routed data).

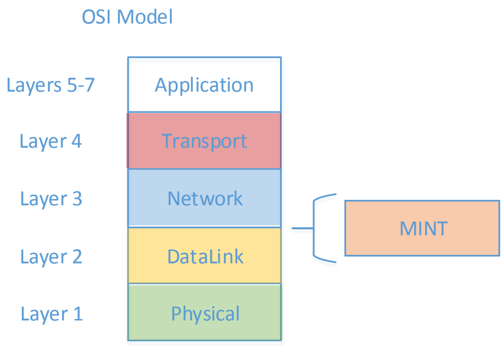
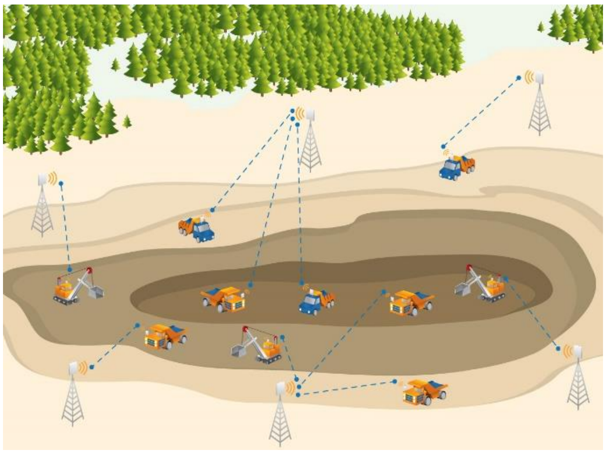


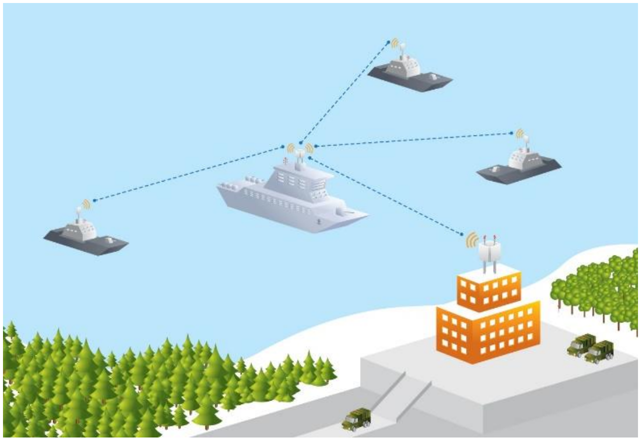
Figure 1 – MINT position

2.3. Mobility scenarios

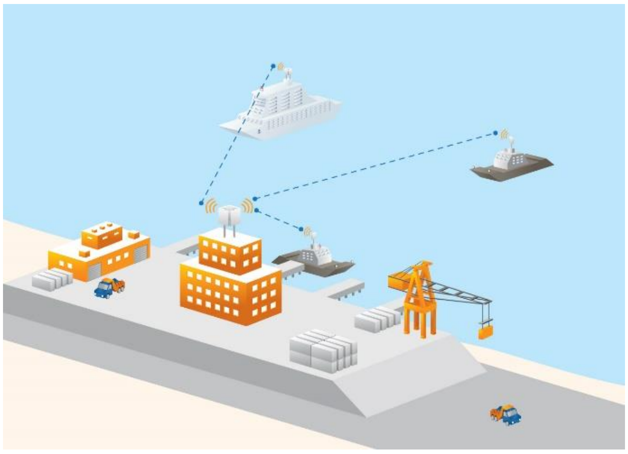
MINT unique advantages allows IW units to be used in various mobile scenarios



Fast switching between different BS within the coverage zone



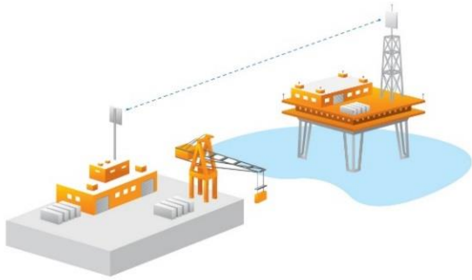
No data loss retransmission point for other vessels



Offshore connectivity with no manual alignment

Automatic adjustment of radio parameters even for Railway

HD video surveillance transmission for emergency service



Over-the-water links

Figure 2 – Mobile scenarios

2.4. MINT technology overview

2.4.1. Where MINT is available

Only adjacent neighbor connectivity is needed to create MINT powered link:

- For radio interfaces

MINT is enabled by default, only radio parameters should be configured.

- For Ethernet interfaces

MINT-over-Ethernet should be enabled manually (disabled by default) for Ethernet interfaces. It is supported by additional virtual Pseudo-radio interface (PRF). Every BS or CPE supports such interfaces.

2.4.2. MINT path selection

In case of multiple MINT routes the protocol would always choose one route for single data frame and would have possibility to re-select new route for another data frame in case of any change of path characteristics. Path characteristics are described by aggregated parameter **MINT cost.**

MINT cost is calculated from the following parameters:

- Signal-to-Noise ratio (for connectivity over radio interfaces)
- Throughput or Bitrate (for connectivity over radio interfaces)
- Percentage of retries
- Link load and throughput
- Some other parameters.

Link quality assessment:

- Each MINT unit has full MINT map with all MINT neighbors
- Each MINT neighbor constantly checks MINT cost between each other
- Each check is to be done each 1-3 s
- MINT path can be predictably changed due to change in link quality (cost drop).

Loop free capability:

- The path for data frame is selected by the lowest overall cost
- The predefined path is set for every packet, unless any changes in network
- The path for frame or packet can be different
- STP BPDU transmission can be blocked in configuration through any logical interfaces.

2.4.3. MINT path selection capabilities

MINT protocol will quickly adjust to possible changes in critical parameters – re-calculate MINT cost for each path and rebuild the path accordingly. Moreover, due to built-in capability to quickly adopt to changes, even data flow path within MINT network can change rapidly too.

On the picture below shown mesh topology of units. All units run MINT protocol for each interface, hence each connection is handled by MINT protocol. In this case, node J has to send data to node F.

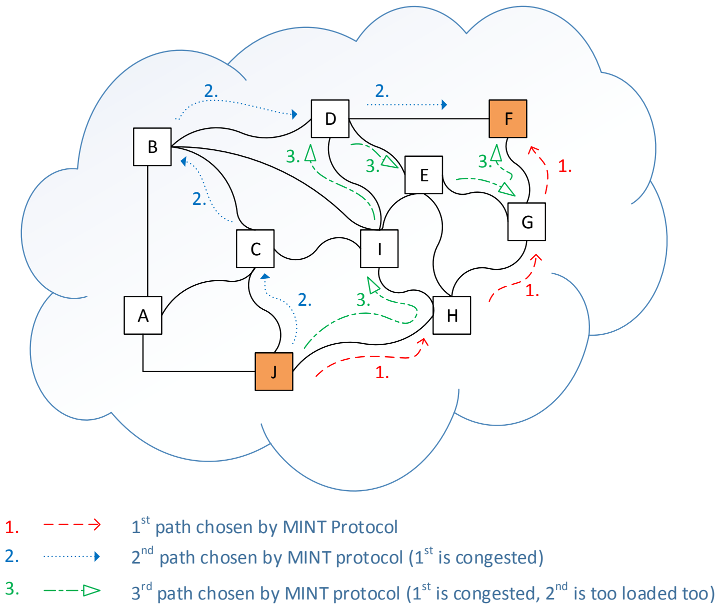


Figure 3 – Mesh topology logical connection scheme

Red path (1st path) has been chosen by MINT protocol initially.

Blue path (2nd path) – MINT decides to switch to 2nd path due to congestion between node H and node G.

Green path (3rd path) – MINT decides to abandon 2nd path too due to excessive traffic load and switch traffic flow to 3rd path.

Each decision to change active traffic path can take place every 1-3 seconds depends on tuning of MINT protocol settings for every unit.

2.5. MINT area

All benefits of MINT protocol mentioned on previous page, would be active ONLY in network from MINT units and with MINT protocol as the only one transport protocol. Such MINT network is called **MINT area**. Thus it is required to create unified MINT area consisting of IW units interconnected by Wireless Radio interfaces (RF) or by Wired MINT-over-Ethernet (Pseudo Radio - in brief PRF) interfaces.

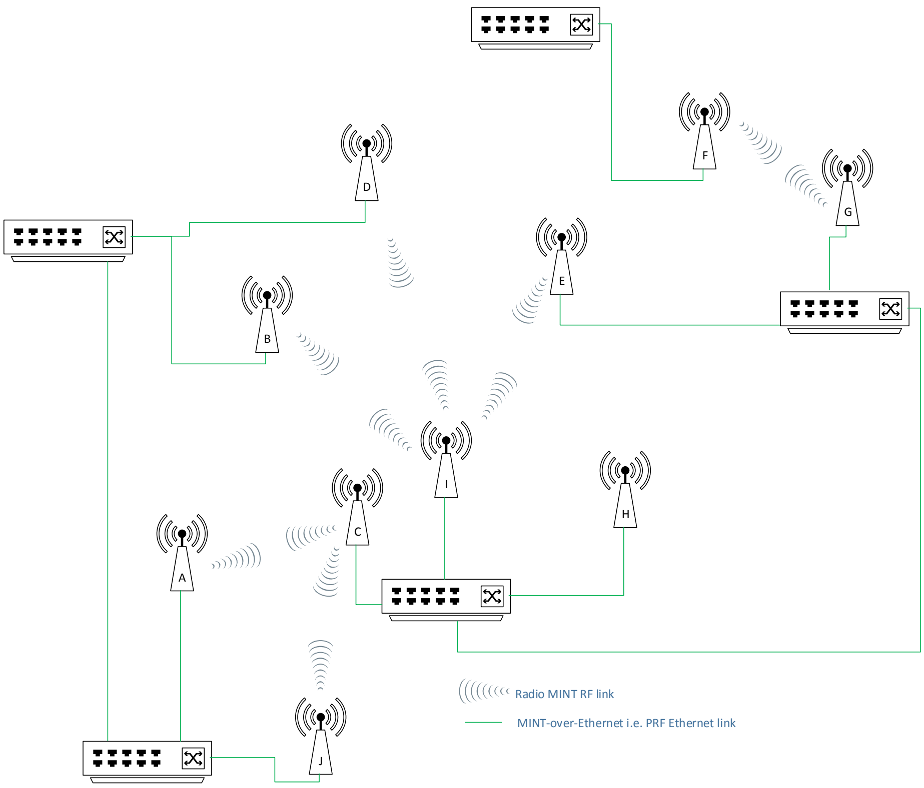


Figure 4 –Connection scheme of physical connectivity by wireless and wired links

Next section contain logical interconnection scheme with RF and PRF links for current physically (wired and wireless) connected units (MINT connections logical scheme).

2.5.1. MINT connections logical scheme

Wireless connection is represented by red link on logical interconnection scheme, wired PRF links are shown in green color.

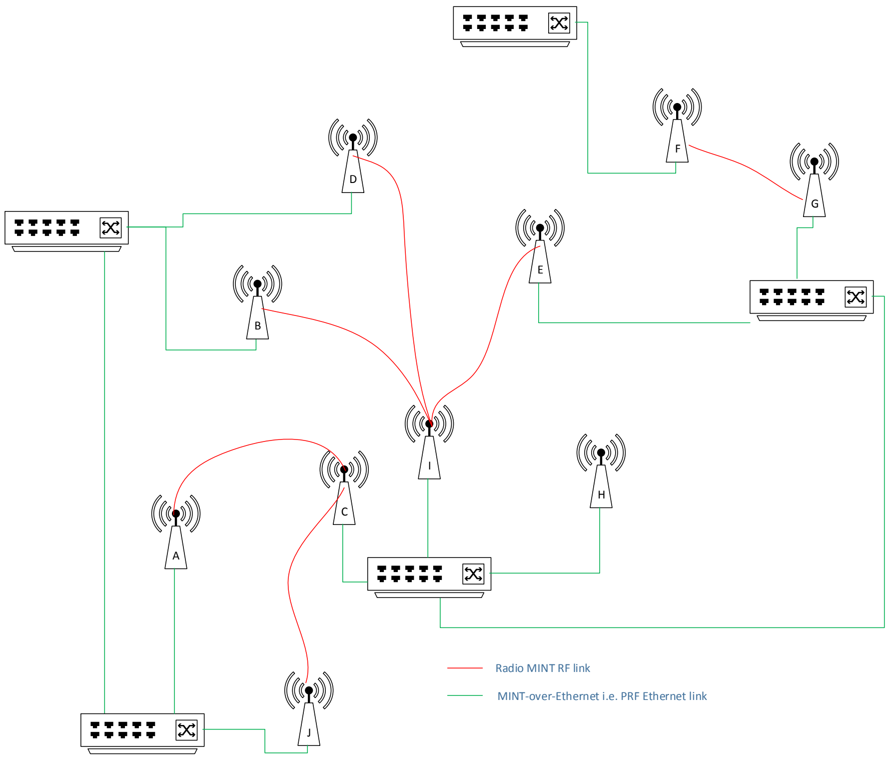


Figure 5 – Connection scheme of logical connectivity by wireless and wired links

So, here we have network where almost each unit has at least two connections via MINT protocol. Therefore, it is possible to balance traffic via one or second path (or even load balance using both). In case of one link failure, another connection would be used as transport. Eventually, under certain circumstances the units can always stay connected because both links down situation is very unlikely to happen. It doesn't really matter what type of physical connection is used (wired or wireless), MINT use any connection. The only thing different is MINT cost value for each link. Let's see how our scheme would look with the exact MINT cost values. We need such representation to figure out which way the traffic will flow.

2.5.2. MINT cost

MINT cost value are shown in **blue box**. Please take into account that MINT cost is independently calculated for each side of the link. Therefore each link (even in PtMP) has two MINT costs.

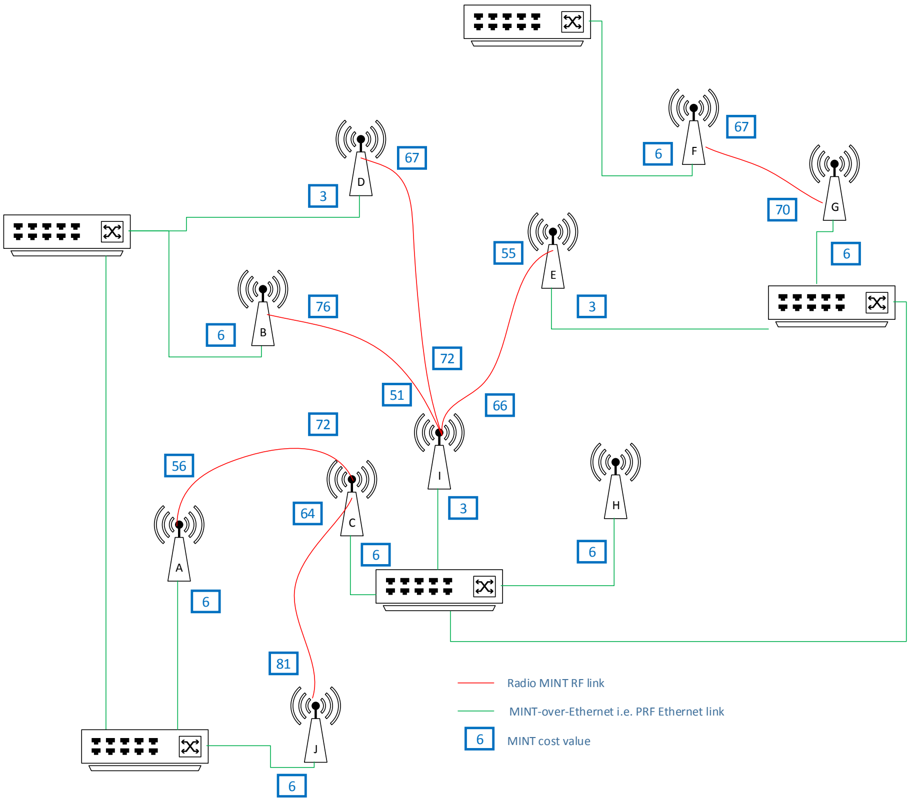


Figure 6 – MINT cost representation on logical connection scheme

MINT cost values are generally speaking has different values for wired and wireless MINT links. As you already know MINT cost is calculated from combination of the following parameters: throughput value, percentage of retries, link load and some other parameters. Thus wired interfaces MINT cost is eventually has more throughput (due to physical Ethernet interfaces speeds 100 Mbps and 1000 Mbps) compared to wireless interfaces (maximum 300 Mbps).

MINT cost is calculated only between MINT enabled interfaces, therefore when calculating MINT cost through switch interconnecting two MINT units – no additional MINT cost added by switch. Switch is transparent for MINT transport.

Traffic flow due to different cost values is show in next section.

2.5.3. Traffic flow due to different cost values

Traffic between nodes J and D flows through MINT wired interfaces due to minimum cost calculated along the whole path:

- MINT cost of node J link to node D equals 6
- The reverse path from node D to node J equals MINT cost 3.

For the sake of simplicity the cost of other MINT interfaces has been omitted.

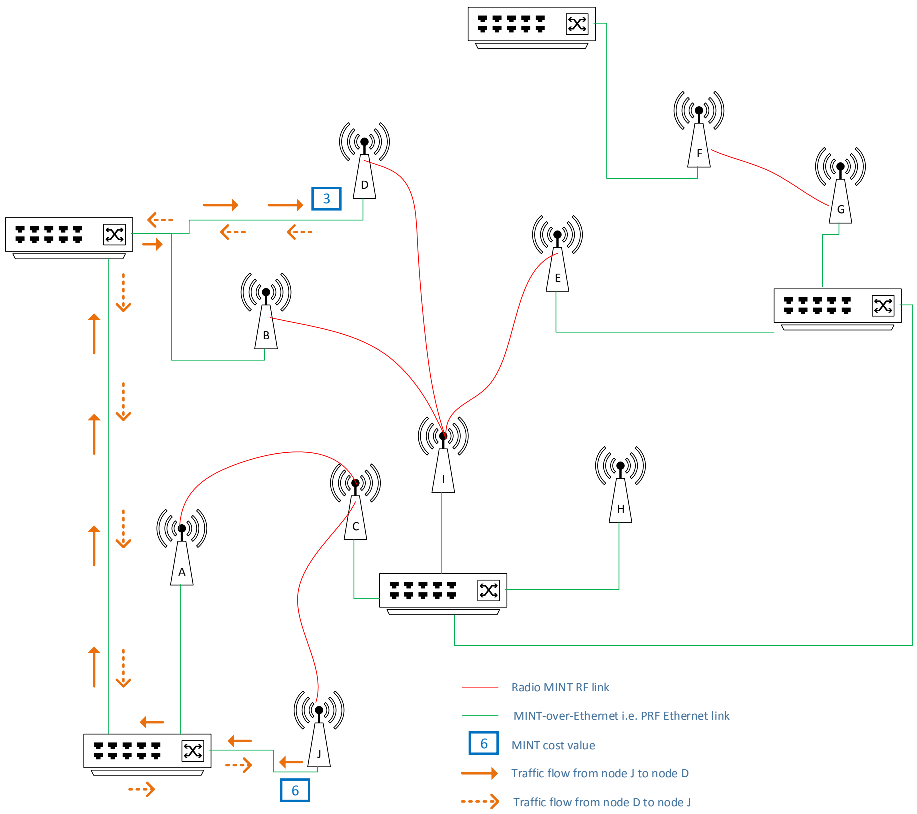


Figure 7 – Simple traffic flow due to MINT costs on logical connection scheme

For sure, mostly the path using wired Ethernet should be more reliable. MINT protocol has use the similar logic.

MINT calculates all possible routes and chooses the most optimal one judging by the link costs sum for each possible route. And this is a continuous process and MINT will recalculate costs in case of any topology or link conditions changes to ensure that the route between any two network nodes is optimal. Moreover, when MINT notice recalculation of MINT cost, using such cost change MINT is able to forecast the situation by switching to alternative routes in case if the situation with active route tends to get worse. Switching between routes takes such a little time that this does not lead for upper layers protocols to break their connections.

More complex path including wireless MINT links is shown on the next section.

2.5.4. Another more complex traffic flow due to the different cost values

Once again the traffic flow choose path with minimum cost. Consider traffic flow between nodes J and F.

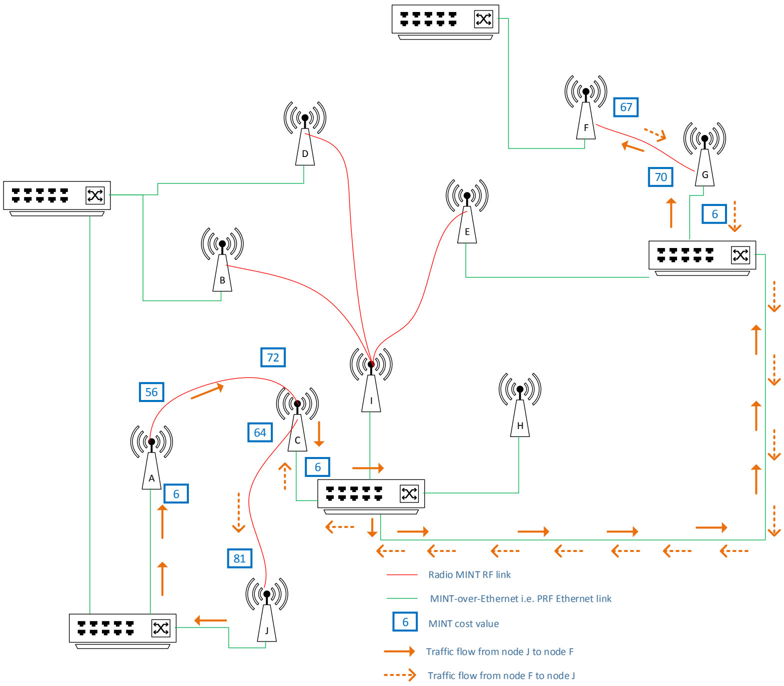


Figure 8 – Complex traffic flow due to MINT costs on logical connection scheme

Total MINT path cost is the summary of cost from node J to node A which equals 6, then from node A to node C which equals 56, then from node C to node G which equals 6 and finally from node G to node F which equals 70:

MINT cost from node J to node F: 6 +56 + 6 +70 = 138

The back route calculation - cost from node F to node G which equals 67, then from node G to node C which equals 6, then from node C to node A which equals 72, and from node A to node J which equals 6:

MINT cost for direct path from node F to node J: 67+6+72+6 = 151

However, unlike previous example (Simple traffic flow…), MINT will select different reverse path.

Total MINT reverse path cost is the summary of cost from node F to node G which equals 67, then from node G to node C which equals 6, then from node C to node J which equals 64:

MINT cost for real path from node F to node J: 67+6+64 = 137

As you can see each path selection depends on values of MINT cost for each interface. Moreover, the initial path and reverse one could not even coincide. Additionally, redundant paths would be used if present. MINT cost can be re-calculated quickly causing change of path selection for traffic. Therefore, MINT provide robust mechanism to adopt link quality degradation or improvements. In case of external interference the units will try to use lower bitrate to sacrifice throughput, but keep current connection operational. Thus, the MINT cost will be changed accordingly. In case of redundant path present and MINT cost of link with interference will quickly exceed the cost to other nodes – thus the traffic flow on link with interference will become very low soon. All the traffic will flow through other path predictively change the data routes before the link having bad interference will finally break down.

2.5.5. MINT area prerequisites

In default configuration MINT protocol is enabled and used only between wireless radio interfaces. However, in order to create interconnected (by MINT protocol) MINT area MINT-over-Ethernet interfaces (PRF) are required.

In order to enable MINT-over-Ethernet it is required to:

- Create virtual Pseudo Radio Interface (PRF). PRF can be created as logical sub-interface for plain Ethernet interface (parent interface) , or as logical sub-interface for another logical interface (for example, VLAN interface can be used as parent interface for PRF)
- Start MINT protocol for PRF interface
- JOIN command connects internal bonds between MINT areas behind Radio interfaces and PRF interfaces.

Within the same Ethernet broadcast domain (LAN) two (or more) IW units with PRF interfaces created, with MINT protocol started can find and establish communication via MINT protocol by sending and receiving Ethernet broadcasts initially. Thereafter, IW units will use Ethernet unicast data transfer.

2.5.6. VLAN considerations

In case two IW are placed within certain VLAN, then configuration of PRF should be corrected with certain VLAN tag. Please pay attention that default configuration (or template part) should exactly use the relevant VLAN tag number.

2.5.7. MINT-over-Ethernet & VLANs

MINT-over-Ethernet does generate broadcast traffic to detect and find other MINT neighbors. Sometimes, such broadcast traffic could be treated as abnormal for network, especially for enterprise networking with comprehensive network security policy.

CAUTION

It is recommended to segment MINT-over-Ethernet connections into dedicated VLAN zones, thus keeping all broadcast traffic within unique VLAN

Moreover, in vast **MINT-over-Ethernet** network different **MINT-over-Ethernet** areas should be isolated from each other in order to provide complex traffic engineering or prevent undesired traffic path selection. Hence, VLAN separation should be used in such cases.

2.6. Switching data with MINT

MINT is closed proprietary protocol. Previously, the operation of MINT protocol own traffic flow was shown. However, in order to transport customer's data – traffic encapsulation technology to MINT is required (to encapsulate Ethernet traffic to MINT when entering of MINT area, to remove encapsulation on exit from MINT area).

In other words, there is a demand to handle transition between MINT and Ethernet or any other protocols.

2.6.1. Switch group

Switch group is special container to work as intermediary between protocols: MINT and Ethernet.

Switch group only works on Layer 2.

Thus, creation of Switch Group creates **Ingress/Egress** point between Ethernet and MINT. Traffic can be switched ONLY between at least **TWO Ingress/Egress** points.

Therefore, in order to have switching of customer's traffic through MINT area, Switch Group configuration should be added to at least two MINT units. Creation of relevant Switch Groups on intermediary MINT units is not required.

Moreover, since the data has been inserted to MINT area by Switch Group, all subsequent actions like transport and path selection are handled by MINT.

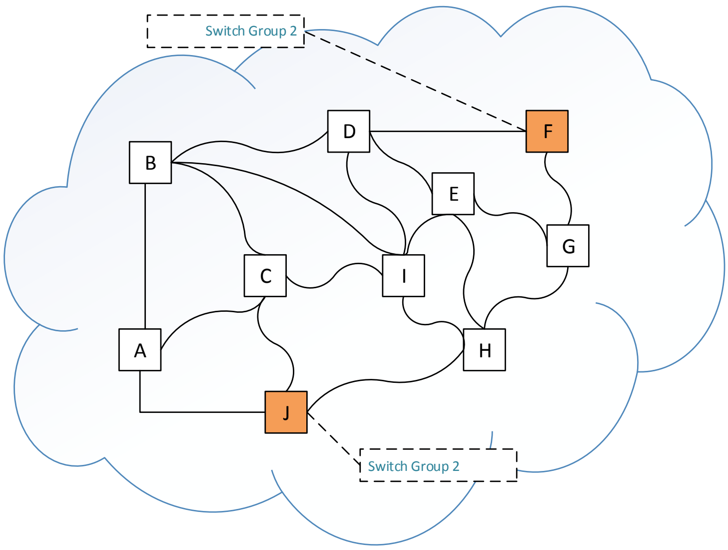


Figure 9 – Switch group scheme

Only units J and F have configuration for Switch Group 2. All other units do not have any switch groups configured. Nevertheless, the data can be successfully switched between J and F.

2.6.2. How Switch Group works

Switch Groups work like tunnels between MINT units.

For example, two units with “Switch group 2” settings create point-to-point MINT tunnel for all Layer 2 traffic between each other for customer (i.e. transit) traffic. Service MINT traffic do not need any switch group configuration.

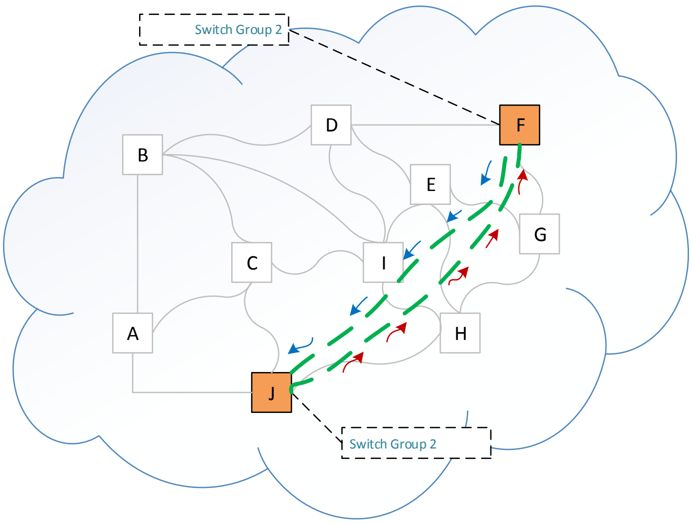


Figure 10 – Example of Switch groups work between two units

Another example, three units have “Switch group 53” configured forming point-to-multipoint MINT tunnel connections between each other on Layer 2 for customer (i.e. transit) traffic.

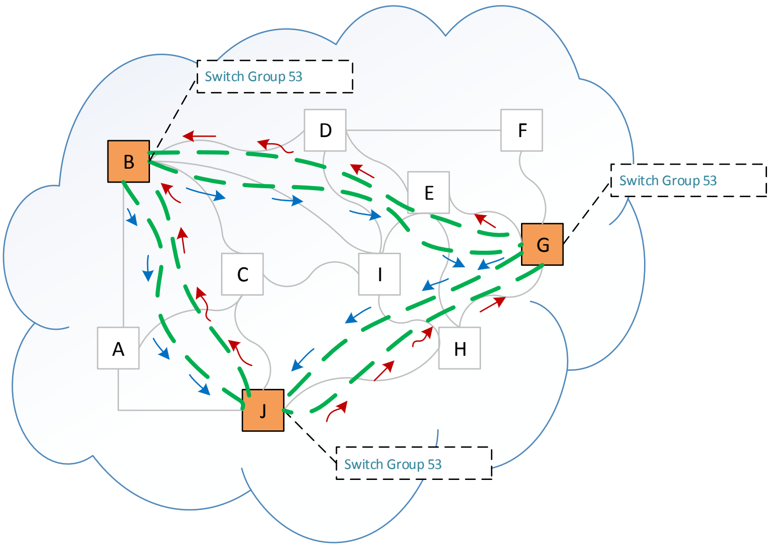


Figure 11 – Example of Switch groups work between three units

2.6.3. Switch Groups Essence

Switch Groups configuration and operation make sense only for border units of the MINT area.

So, MINT provides transport and path selection, while Switch Groups provide logical channels for data switching on Layer 2.

Switch Groups as logical channels can be treated like logical PtP or PtMP tunnels through MINT area.

One IW units can have different Switch Groups configured i.e. different logical channels for different traffic type.

Switch groups connections logical scheme illustrates the above statements.

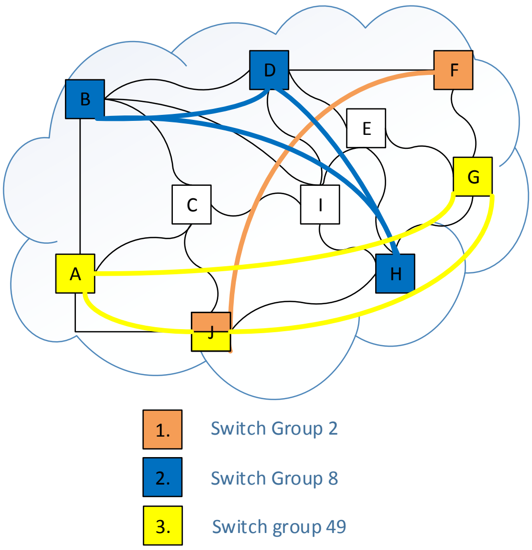


Figure 12 –Switch groups connections logical scheme

Only units J and F has configuration for switch group 2. Units H, D and B have switch group 8. Meanwhile, units J, A and G have switch group 49 configured. So, the unit J has configuration for switch group 2 and 49. Please bear in mind the real traffic flow can take ANY path completely different from logical interconnection, because path selection is determined by MINT protocol via MINT cost.

The unit J is connected by different logical channels i.e. switch groups 8 and switch group 49. However additional filter rules or combination of different switch groups is required to assign different traffic to appropriate switch group. Please read about switch group filter rules in IW documentation: R5000 – WANFlex OS User Manual, section “Rules Configuration Commands”.

NOTE

Product technical documentation is always available on our web site http://infinetwireless.com/products/materials#documentation. Registration is required.

2.6.4. Switch Group capabilities

Switch Groups ID can have numbers from 1 to 4095.

The main purpose of Switch Group is to be container for VLANs.

Meanwhile, it is possible to use Switch Groups as transport for different types of traffic – not only VLANs.

In order to transport different traffic pattern additional filter rules should be used.

Traffic could be differentiated according to the following criteria:

- VLANs
- IP Groups
- MAC address groups
- Traffic with the same values for QoS headers fields
- Multicast traffic
- Different other common criteria
- Or combinations of all above.

Please pay attention, Switch Group number should coincide on both units to switch the data between them.

In the above example, switching could happen ONLY between Switch Group 2 on J and between Switch Group 2 on F.

There is no way to change Switch Group number while the data travels through MINT network.

2.6.5. Switch Group structure

Switch Group have at least one logical interface. One interface in Switch Group could be used as management interface.

Switch Group have two interfaces or more to provide services to customer network. Therefore, the data would be switched between these two (or more) interfaces.

Interfaces in Switch Group could be:

- Physical Ethernet ports – eth interface
- Radio port – rf5.0 interface
- Special Switching management interface – SVI interface

- Auxiliary interface for VLAN handling – VLAN interface
- Pseudo Radio interface for MINT-over-Ethernet – PRF interface
- Aggregation interface – LAG interface
- Tunnel interfaces – TUN, TAP interface.

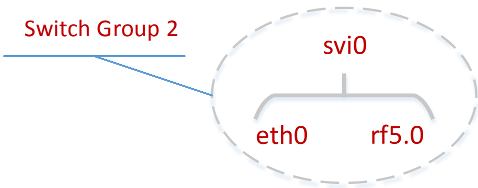
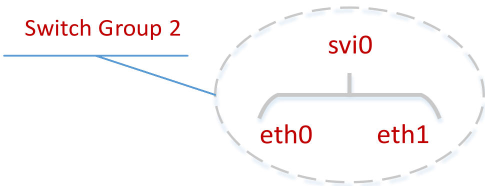
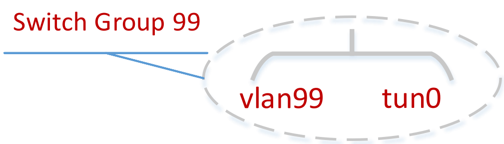
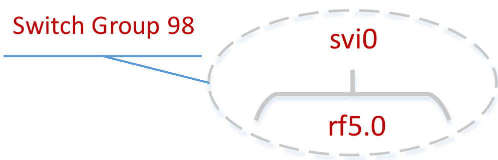
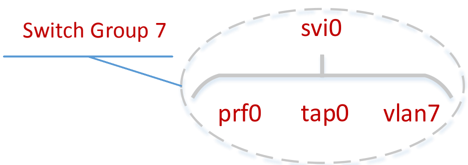
Switch group examples	Description
	Important notice: Special SVI interface is Switch Group Virtual interface which could be linked with any Switch Group and send/receive management and monitoring data through the Switch Group, while the unit operates in Switch mode
	Switch Group can combine different interfaces: Switch Group acts like a switch for eth0 and eth1: the packets could be switched between these interfaces in wired Ethernet segment
	Switch Group can switch frames between different interfaces depending on to technical task to be solved. SVI is used to send management and monitoring data within the Switch Group, therefore SVI is not needed in Switch Group intended for customer traffic
	Switch Group can consist only from one interface to provide only management
	Switch Group can encompass a lot of interfaces and the frames would be switched between all listed (in Switch Group) interfaces

Table 1 – Switch Group examples

Consequently, the logical scheme for the Point-to-Point connection

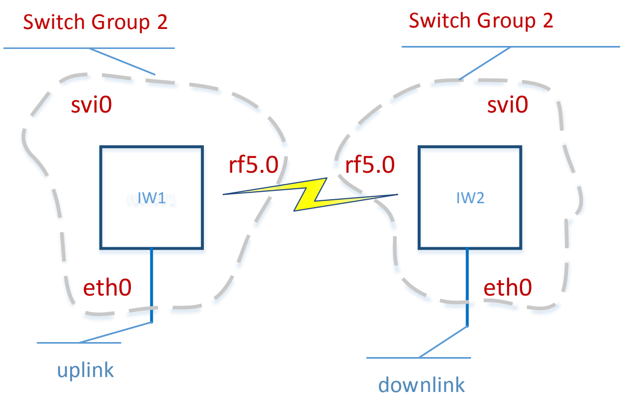


Figure 13 – Point-to-Point connection logical scheme

Configuration of Switch Group includes:

- Ethernet interface – eth0
- Radio interface – rf5.0
- And SVI interface for management – svi0.

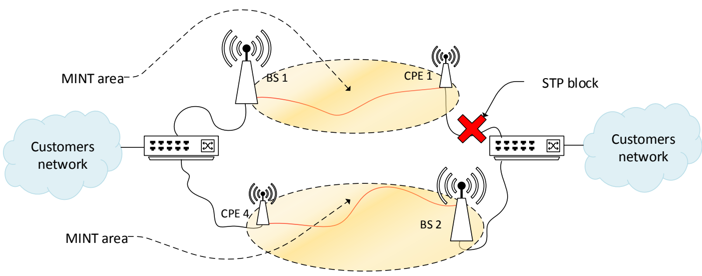
2.7. MINT & topologies

Simple example topologies are shown below to demonstrate MINT benefits described. Using the combination of units with enabled PRF interfaces it is possible to create even combinations of MINT areas networks with high level of redundancy, reliability and traffic load-balancing with permanent link quality check for each available link (no matter wireless or wired one).

Load-balancing

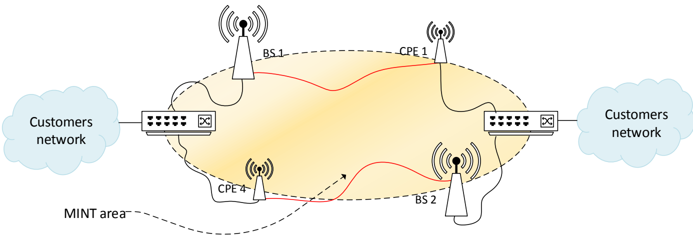
2 parallel L2 links

Simple load-balancing scheme will utilize only one link, cause the second link will be blocked by Spanning-Tree protocol (STP) to avoid switch loop



2 parallel L2 links with MINT-over-Ethernet

Unlike the above generic example, MINT-over-Ethernet helps to single MINT area and utilize both links without STP



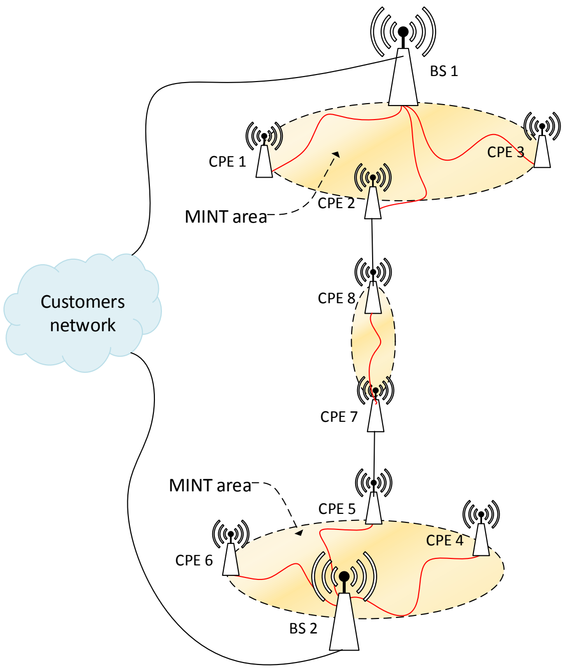
Redundancy

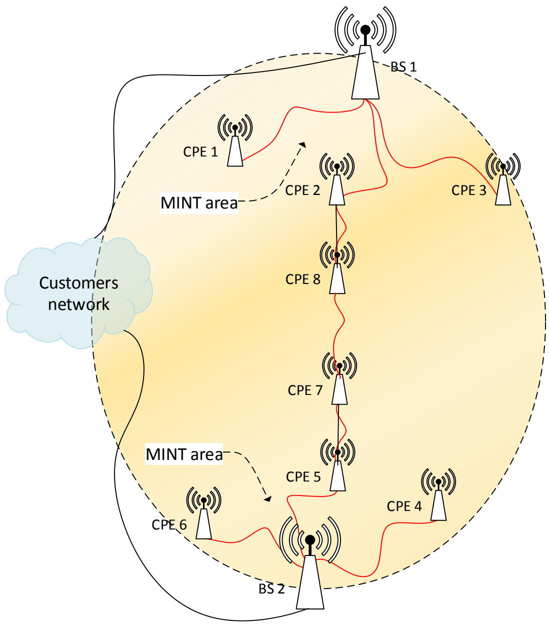
Interconnection of 2 PtMP

Additional redundant path will be used mostly only during failure of BS1 or BS2 uplink to Customers network

Interconnection of 2 PtMP with MINT-over-Ethernet

With MINT-over-Ethernet once again single MINT area will be used everywhere, thus always MINT will have possibility to use either uplink to BS1, BS2, or interconnection path via CPE 7, CPE 8.





2.8. Infrastructure MINT mesh unit

Initially MINT was designed for mesh connections. Meanwhile, it is impossible to create real mesh network using IW units (due to license policy and only 1 radio interface on unit), nevertheless MINT shows significant advantage in creation of **Infrastructure MESH objects**.

Such objects consist from at least two IW units interconnected by PRF interfaces.

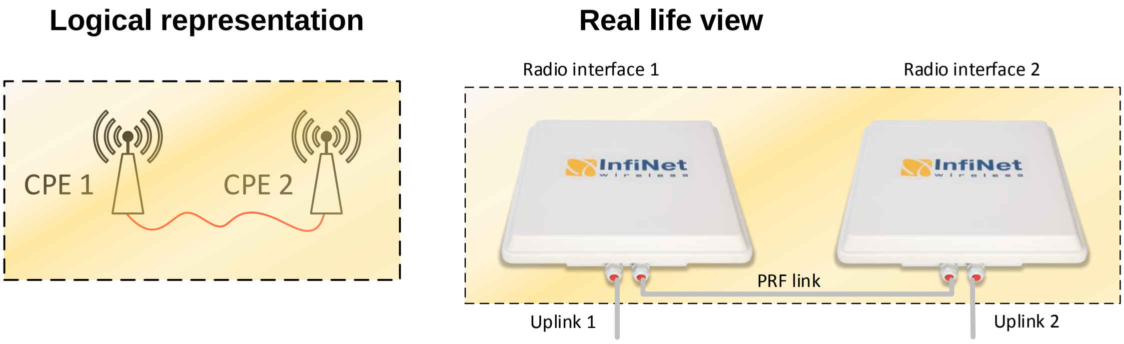


Figure 14 – Two IW units interconnection

What are the benefits of such “Lego”-Infrastructure MINT mesh object?

- Infrastructure MINT mesh object consisting of two or more devices. Each device add additional wireless radio to unit, thus increase reliability and availability. Infrastructure MINT mesh object can have two, three, four, five radio interfaces (and even more) each operating on separate frequency
- Load balancing using ALL available links (Wireless and Wired). Specially modified proprietary virtual aggregated interface (LAG interface in proprietary “fast” mode) can be enabled to utilize all available links
- Self-organized and self-sustained mobile network for different scenarios. Such as mining, ferries, oil & gas projects. You only pay for infrastructure in the beginning. Further there won’t be any operational rentals expanses.

More flexibility can be achieved using Infrastructure MESH object from connectorized units or from combination of connectorized unit with integrated antenna unit.

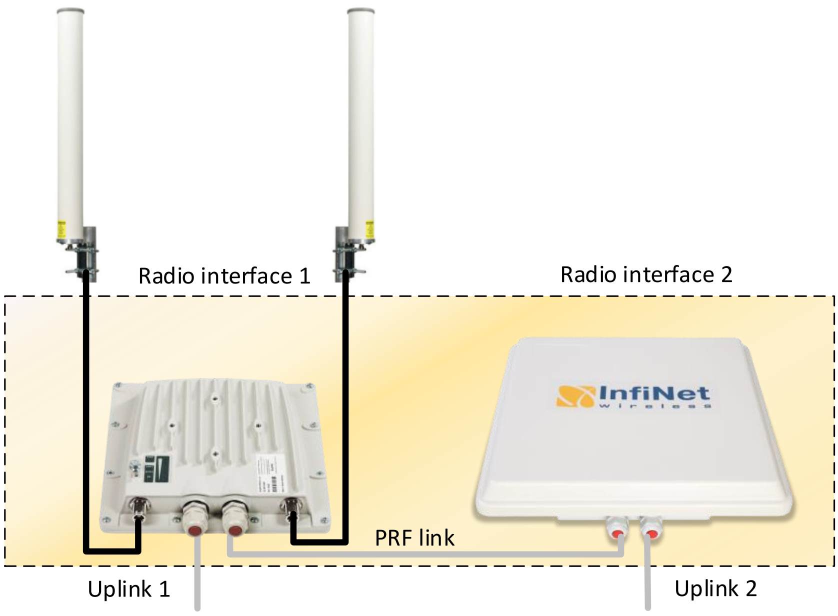


Figure 15 – Mobility Infrastructure MINT mesh object

Such Infrastructure MESH objects can be equipped with Omni antennas and provide reliable and almost handover capabilities during switch of connection to different BS without data flow interruption. The operating range of such units with different antennas combination (2 IW units can have 4 different antennas combined) can operate within 1-3 km coverage area. Different antenna type can be used to overcome different terrain profile changes.

Second example of Infrastructure MESH objects is more complex for providing 360 connectivity for vessel. Each IW unit has sector 90° or 120°antenna.

Such **sea mobile Infrastructure MESH objects** provide connectivity for the ferry up to 40 km or even up to 70 km (combined with land BS equipped by narrow beam high gain antennas).

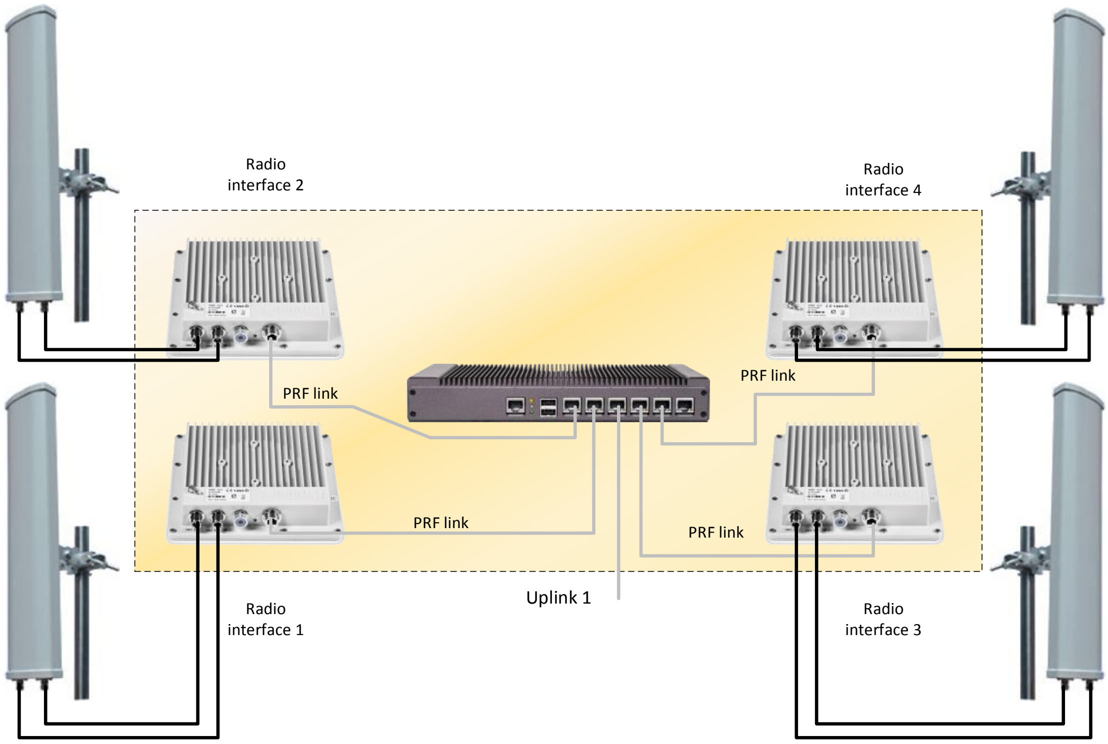


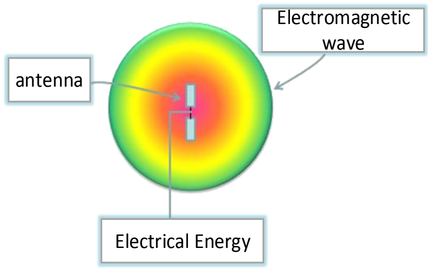
Figure 16 – Sea mobile Infrastructure MINT mesh object

Antennas

Chapter 3

3.1. Antennas considerations

Antenna. An antenna is a passive device which does not offer any added power to the signal. Instead, an antenna simply redirects the energy it receives from the transmitter. The redirection of this energy has the effect of providing more energy in one direction, and less energy in all other directions.



An antenna is a transducer between a guided wave and a radiated wave, or vice versa. The structure that "guides" the energy to the antenna is most evident as a coaxial cable attached to the antenna. The radiated energy is characterized by the antenna's radiation pattern.

There are various types of antenna out there, some of the examples are shown below. These are only some examples and there are a lot of other types as well. Just check how many of these you are familiar with.

Figure 17 – Examples of antennas

3.1.1. Antenna Performance evaluation

Two major tasks to solve for best antenna performance:

- The electrical signal should be converted to Electro-Magnetic radiation energy as little loss as possible

- The Electro-Magnetic radiation energy should be transmitted as much as possible only to the designated direction.

There are four quantitative indicators to represent the performance of an antenna:

- Antenna radiation pattern
- Gain
- Direction
- Polarization.

3.1.2. Antenna radiation pattern

The first step to understand/evaluate the performance of an antenna is to check the radiation pattern of the antenna. Electrical energy flows through a predefined path in most case built in a copper cable or copper trace on PCB, but once the energy is converted into electromagnetic wave, it propagate into the air almost in every direction. Depending on design of the antenna, the direction in the air in which electromagnetic wave propagate varies. In some direction, the antenna transmit very strong energy and in some direction it transmit small amount of energy and in some direction it transmit the medium range of energy etc.

This kind of energy transmission pattern is called **Radiation Pattern.**

In discussions of antenna patterns, the terms azimuth plane pattern and elevation plane pattern are widely implemented. The term azimuth is commonly found in reference to the "horizon" or the "horizontal" whereas the term elevation commonly refers to the "vertical".

Antennas and their radiation patterns in different planes are shown in the table on the next section.

3.1.3. Most common radiation patterns

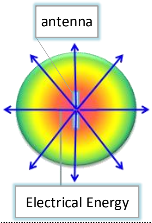
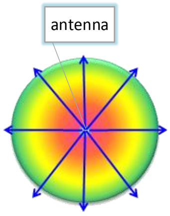
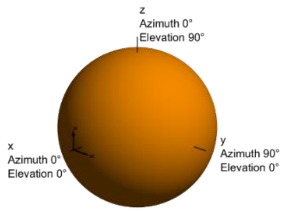
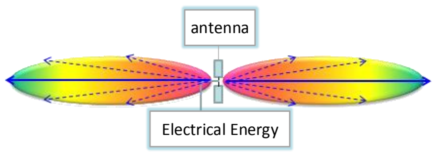
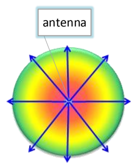
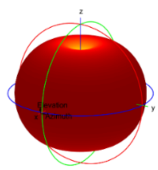
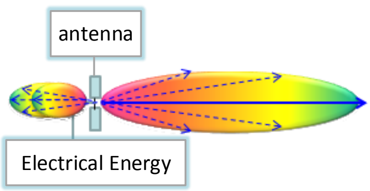
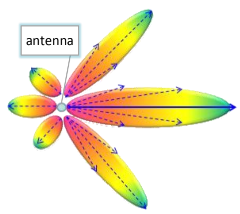
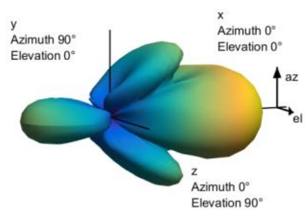
<table>
<tr><td colspan="3">Isotropic imaginary antenna (which does not exist in reality) represented by single point, propagates equally around 360°</td></tr>
<tr><td colspan="3">Radiation pattern</td></tr>
<tr><td>Side view</td><td>Top view</td><td>3D view</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Omni antenna</td><td></td><td>The azimuth plane pattern is formed by slicing through the 3D-pattern in the horizontal plane, the x-y plane in this case, just as you would slice through a bagel. Notice that the azimuth plane pattern is non-directional, that is, the antenna radiates its energy equally in all directions in the azimuth plane. So the azimuth plane pattern is a circle, passing through the peak gain at all angles</td></tr>
<tr><td colspan="3">Radiation pattern</td></tr>
<tr><td>Side view</td><td>Top view</td><td>3D-view</td></tr>
<tr><td>
</td><td>
</td><td></td></tr>
<tr><td>Directional antenna</td><td></td><td></td></tr>
<tr><td colspan="3">Radiation pattern</td></tr>
<tr><td>Side view</td><td>Top view</td><td>3D-view</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 2 – Antennas types, Radiation pattern and description

So radiation pattern shows the difference in forming of electromagnetic wave out of antenna. Omni directional antenna produce good 360° horizontal coverage, but the signal is not propagated strongly in vertical direction. On the other hand directional antenna concentrates most signal propagation to one selected direction.

3.1.4. Radiation pattern Lobes

Any given antenna radiation pattern has portions of the pattern that are called lobes. A "lobe" can be a main lobe, a side lobe or a back lobe and these descriptions refer to that portion of the pattern, in which the lobe appears. In general, a lobe is any part of the pattern that is surrounded by regions of relatively weaker radiation.

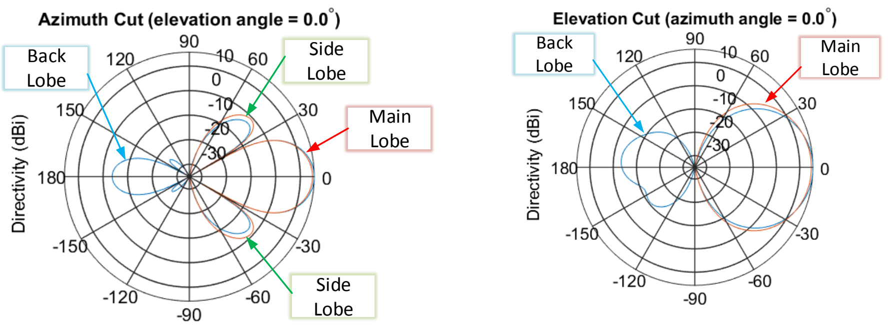


Figure 18 – Directional antenna planes

3.1.5. Antenna Gain

Antenna gain is not amplification of signal, thus it is a little bit incorrect. Antenna is merely passive device, which does not amplify anything. Higher gain to antenna term mean: more energy transmitted in a certain direction, however don't forget of course antenna always transmit electromagnetic wave to all directions.

Just less amount of energy transmitted to other directions, especially in case of directional antenna. The definition of antenna gain is the ratio of power transmitted in a certain direction to a certain reference point. This is usually expressed in dB or dBi. The "i" in "dBi" specifies the reference level, which in this case is a hypothetical isotropic antenna that transmits a signal in a perfect sphere. This antenna has a gain of 0 dBi since it's the reference point. In real life it's impossible to make such an antenna. dB is a logarithmic unit and every 3 dB increase is a doubling of the power (intensity). This means that if you switch out your theoretic 0 dBi antenna for a 3 dBi antenna you will gain the same amount of extra range as doubling your transmitter output power.

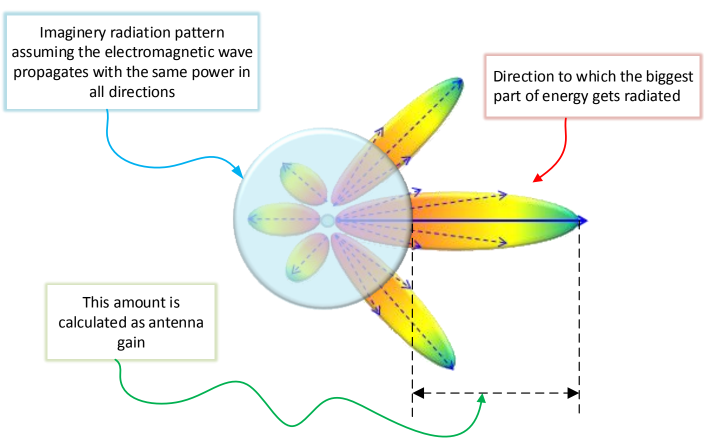


Figure 19 – Antenna gain

Gain is a measure of increase in power. Gain is the amount of increase in energy that an antenna adds to a radio frequency (RF) signal.

Following figure represents the rule of thumb propagation pattern for typical Gain values. As you see, as Antenna gain increases the direction of propagation gets more and more focused, it does not mean that the total transmission energy (the area surrounded by the ovals) gets higher.

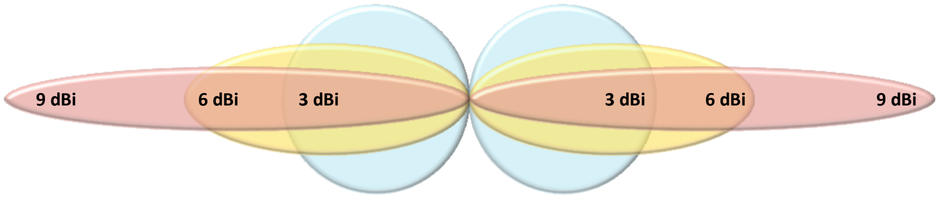


Figure 20 – Thumb propagation pattern for typical gain values

3.1.7. Polarization

Electromagnetic wave is characterized by travelling in a single direction (with no field variation in the two orthogonal directions). In this case, the electric field (E) and the magnetic field (H) are perpendicular to each other and to the direction the plane wave is propagating. Electric (E) and magnetic fields (H) can be represented by vectors which have an amplitude and a direction. Cartesian coordinate system (X,Y,Z) that means that the direction of the E and H field are in the XY plane. Therefore, the direction of propagating electromagnetic wave travelling in the Z direction the electric (E) and magnetic (H) fields are described in the plane perpendicular to the direction of propagation.

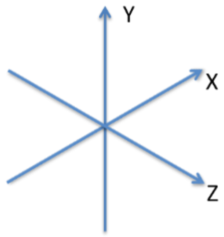


Figure 21 – Coordinate system

All IW units use antennas with linear polarization. Linear polarization means the antenna can radiate in only one plane, either horizontal or vertical. Left figure represent horizontal, right – vertical.

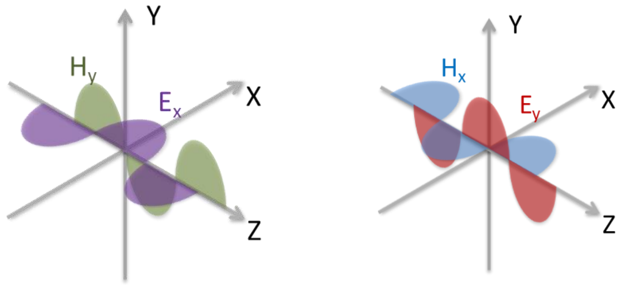


Figure 22 – Linear polarization

Whenever you take a linear polarized antenna and turn it 90° it changes it's polarization. If it's inline with the horizon it's horizontally polarized, hence the name. The trouble is that when a vertically polarized antenna tries to communicate with a horizontally polarized antenna (this is called cross-polarization), and vice versa, you get a 30dB loss in signal strength (which is a lot!).

All IW equipped with MIMO dual-polarized integrated antennas (so the radio device and antenna mounted into one solid unit). Hence, two polarization shifted between each other to 90° are formed by single antenna. MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. Data is sent and received on both the horizontal and vertical polarizations. Different data is being send by vertically polarized signal and horizontally polarized signal simultaneously, thus doubling the throughput of the radio link.

3.2. Antenna selection

Three different scenarios are possible:

- Fixed – BS and CPE location are stable. No movement for all objects
- Nomadic - nomadic scenarios the CPE position may change in relation with the BS periodically and the data transfer takes place at a stationary position
- Mobile - CPE constantly changes its position in relation with the BS and data transfer occurs during movement.

3.2.1. Fixed scenario

Common **fixed** deployment scenario of every project: BS with sector (wide beam) antenna and CPE with (narrow beam) directional antennas.

Figure 23 – Fixed scenario

Main idea is to have sufficient BS coverage zone. In case of low signal strength of CPE on reception on BS, it is recommended to increase CPE antenna gain by replacing CPE antenna. For higher throughput it is recommended to have clear Line-of-Sight between BS and CPE.

3.2.2. Nomadic scenario

In **nomadic** projects directional antennas can be used, however such projects require re-alignment each time after location change, or automatic alignment system should be considered (example describe further in Offshore communication chapter).

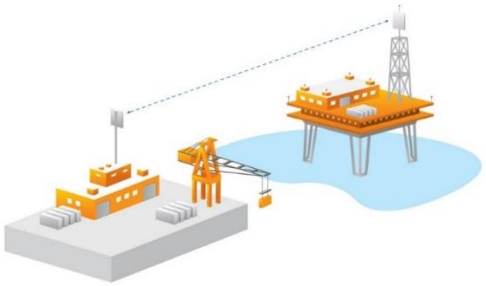


Figure 24 – Nomadic scenario

3.2.3. Mobile scenario

Finally, mobile projects are unlikely to use directional antennas on CPE (except along with automatic alignment system Offshore communication). However, some projects could use even fixed directional antennas (but for BS). Nevertheless, most of mobile projects are possible with Omni antennas. Omni antennas are capable to send and receive signals from each direction, however the total antenna gain cannot be high.

Figure 25 - Mobile scenario

3.2.4. Omni antennas

Omni antennas do not need alignment since their radiation cone is 360 degrees, working in all directions. The radiation pattern of Omni antenna in 3D view pattern looks kind of like a donut or a bagel with the antenna sitting in the hole and radiating energy outward. The strongest energy is radiated outward, perpendicular to the antenna in the x-y plane.

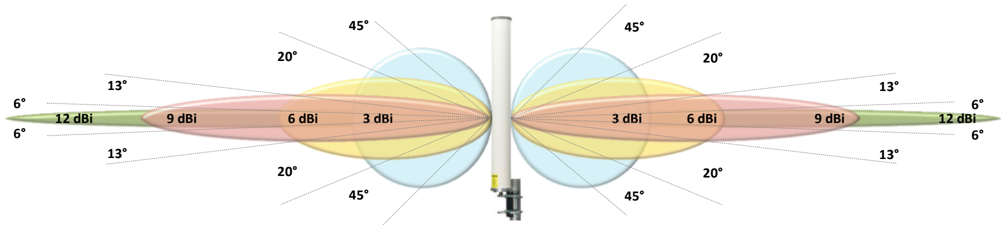


Figure 26 – Omni antenna radiation pattern

Gain contradicts with coverage. The more gain you have, the narrower coverage zone becomes:

- 3 dBi = 45° elevation – however, the coverage distance is very short
- 6 dBi = 20° elevation
- 9 dBi = 13° elevation
- 12 dBi = 6° elevation – however, the coverage zone depends too much on elevation.

Given these antenna patterns, the Omni antenna should be mounted so that it is vertically oriented with respect to the floor or ground. This results in the maximum amount of energy radiating out into the intended coverage area. The null in the middle of the pattern will point up and down.

Provided values have been used only for reference.

Careful attention must be paid to the vertical dispersion (elevation) of the Omni antenna, which sometimes is unacceptable or even impossible.

Therefore, it is impossible to use Omni antennas for BS units. Sector antennas for BS should be used instead. Omni antennas are applicable ONLY to subscriber units.

3.2.5. Sector antennas usage

Now let's take a more thorough look to **sector** antenna radiation pattern at different planes.

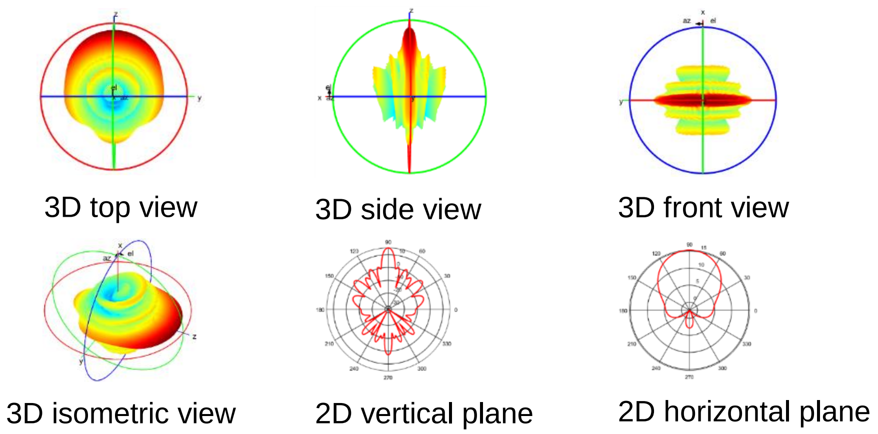


Figure 27 – Sector antenna radiation pattern

One of the problems encountered when deploying omnidirectional antennas for mobility, is that there can be several nulls in the elevation plane. For antennas mounted high in the air on towers, these nulls can affect the performance of the system.

Assume that the sector antenna is mechanically tilted down by 7 degrees. This effectively tilts the elevation plane pattern down 7 degrees as shown. This puts certain regions under the antenna in areas below the nulls in the pattern resulting in areas of low signal strength.

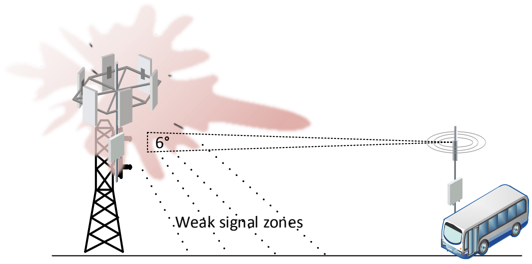


Figure 28 – Example of performance for plain ground profiles

Combination of **sector** antennas for BS and **Omni** antennas for subscriber units provide best performance for plain ground profiles especially along established routes. For examples, for mobility train projects – Omni antenna is the best match. However, for the mobility projects with hills, big difference in ground elevation (mines, for example) – Omni antenna could result in poor performance or even to frequency disconnects and to presence of no coverage zones.

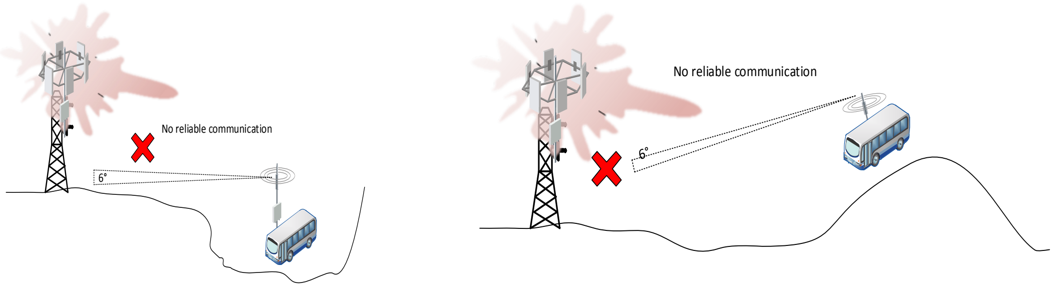
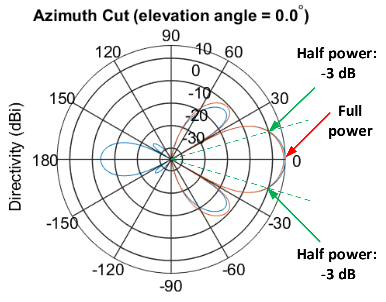


Figure 29 – Example of performance for the project with hills, big difference in ground elevation

3.2.6. Directivity

Directivity affects the shape of the transmission pattern. As the gain of a directional antenna increases, the angle of radiation usually decreases. This provides a greater coverage distance, but with a reduced coverage angle. The coverage area or radiation pattern is measured in degrees. These angles are measured in degrees and are called beamwidths. Beamwidths are defined in both horizontal and vertical plains. Beamwidth is the angular separation between the half power points (-3 dB points) in the radiation pattern of the antenna in any plane. Therefore, for an antenna you have horizontal beamwidth and vertical beamwidth.

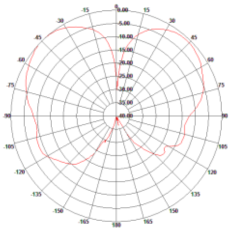


The -3 dB beamwidth (or half-power beamwidth) of an antenna is typically defined for each of the planes. The -3 dB beamwidth in each plane is defined as the angle between the points in the main lobe that are down from the maximum gain by 3 dB. The -3 dB beamwidth in the plot in this figure is shown as the angle between the two green dashed lines in the polar plot.

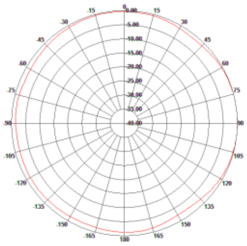
Antennas with wide beamwidths typically have low gain and antennas with narrow beamwidths tend to have higher gain.

3.2.7. Shark wave antenna advantage

Such low performance of Omni antennas could be mitigated by switching to shark wave antennas. Radiation pattern of shark wave antennas looks similar to Omni, however small difference plays huge role in performance, especially for mining industry.



Side view

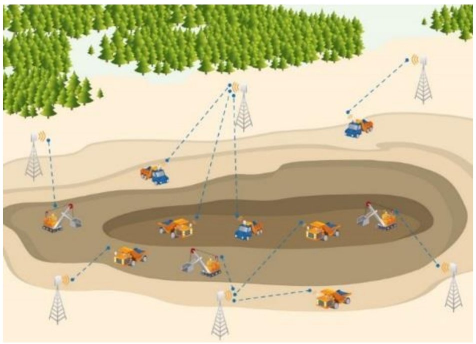


Top view

Figure 30 – Shark wave antenna

Since most of the radiation is directed up on vertical plane and on horizontal plane the radiation is spread universally in all directions, such shark wave antennas plays major role in mining mobility projects.

Combination of shark wave and Omni antenna is the preferred approach for such projects. Omni shows better results on plain horizontal ground profile, shark wave adds betters signal reception and transmission for locations with variable elevation.

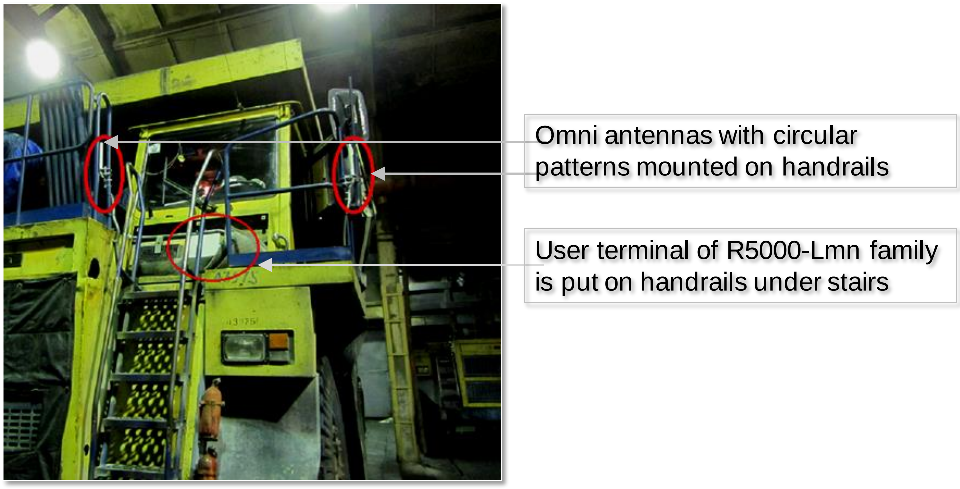


3.3. Antenna diversity

Antenna Diversity is a transmission method using more than one antenna to receive or transmit signals along different propagation paths to compensate for multipath interferences. Due to multipath propagation interference effects between network nodes, the receive signal strength may strongly vary, even for small changes of the propagation conditions, affecting the link quality. These fading effects can result in an increased error floor or loss of the connection between devices. Applying Antenna Diversity transmission techniques in such scenarios improves the reliability of an RF connection between network nodes.

3.3.1. Space diversity

Diversity is the use of two antennas for each radio, to increase the odds that you receive a better signal on either of the antennas. The antennas used to provide a diversity solution can be in the same physical housing or must be two separate but equal antennas in the same location. Diversity provides relief to a wireless network in a multipath scenario. Diversity antennas are physically separated from the radio and each other, to ensure that one encounters less multipath propagation effects than the other.



Diversity antenna placement relies on the probability that if one antenna is inside a null, an antenna somewhere else will not be in the same null. And this is true for an individual dead spot. But nulls exist in multiple locations, and can exist quite close together, and in all sorts of complex shapes and sizes. Spacing the distance of 1/2 a wave apart will do the job. The likelihood of reducing multi-path interference events will be lower than it would be were you to use a single antenna, but it is not a magic number.

3.3.2. Polarization Diversity

Fading characteristics are dependent on polarization. A signal can be transmitted and received separately on horizontal and vertical antennas (combined in single dual polarized antenna) to create two diversity channels. Reflections can cause changes in the direction of polarization of a radio wave, so this characteristic of a signal can be used to create two separate signal channels. Thus, cross-polarized antennas can be used at the receiver only. For instance, dual polarized antenna can be used for BS.

All IW units use Multiple-Input and Multiple-Output (MIMO) technology, which are systems with multiple antennas at the transmitter and receiver. So in case of IW 2x2 MIMO – two independent transmitters (and receivers) used to send (and receive) data using two different spatial streams simultaneously. Eventually, MIMO 2x2 can transfer twice more data then system with only one transmitter (and receiver). Different polarization helps to create two spatial independent radio streams within one unit and one dual-polarized antennas, for example, both (vertical and horizontal) polarized signals are used to transmit at the same moment DIFFERENT data streams.

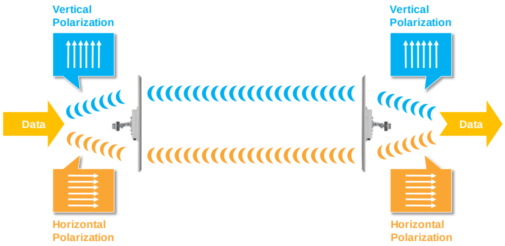


Figure 31 – MIMO: both (vertical and horizontal) polarized signals are used to transmit at the same moment DIFFERENT data streams

However, it is preferred to use Multiple-Input and Single-Output (MISO) technology in mobility projects.

Reflections could cause vertical polarization transmitted from one unit to be received by horizontal receiver of the other unit. Also, such polarization swap could happen constantly all the time. However, this effect could be easily solved by switching Infinet units to special MISO mode. MISO mode in IW implementation results in simultaneous transmission of the same data signal using both (vertical and horizontal) polarizations, hence on the reception side the unit receives the same data to both (vertical and horizontal) transceivers. The effect is less than half the throughput, however this mode significantly improves signal reception quality and doesn't care about polarization swap effect. MISO mode is extremely helpful to 'stabilize' the link especially when the units works with reflected signals, especially while CPE moves.

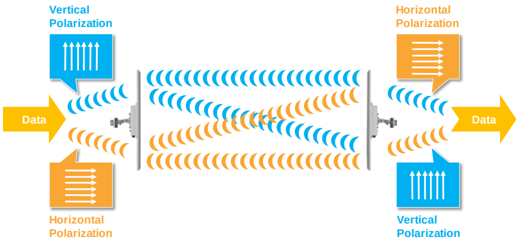


Figure 32 – MISO: both (vertical and horizontal) polarized signals are used to transmit at the same moment SAME data stream

Space diversity is recommended for CPE units (two Omni antennas for both transceivers) and polarization diversity with MISO mode for dual-polarized sector BS antenna.

Let’s see how MINT and MINT-over-Ethernet works. Example Point-to-Point will be considered on next pages.

Examples

Chapter 4

4.1. Point-to-Point example

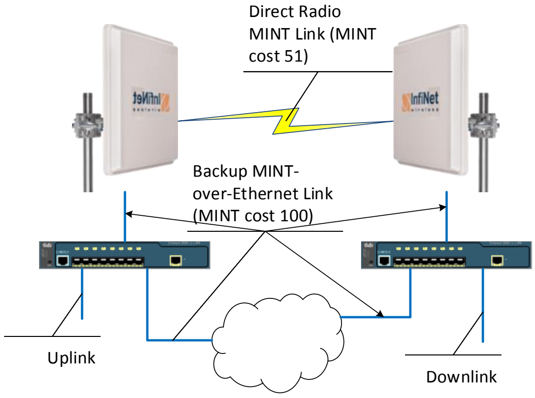


Figure 33 – Topology diagram of wireless link with backup MINT-over-Ethernet link

The preferred path would be chosen by lowest MINT cost value. Therefore, Radio Link will be the main one. Meanwhile, in case of Radio Link Signal degradation – the MINT cost value would decrease very fast and could pass threshold value to lead to backup Ethernet path selection.

Let's, consider the traffic data path in two stages:

- Stage One: Radio link experience no problems and MINT choose it as main path
- Stage Two: Problems on radio link thereafter MINT chose Ethernet backup path.

4.1.1. Stage One: Radio link is main path

Arrows represents traffic path. Different color represents data with and without additional MINT information in frame headers. Numbers along with arrows represents path stage.

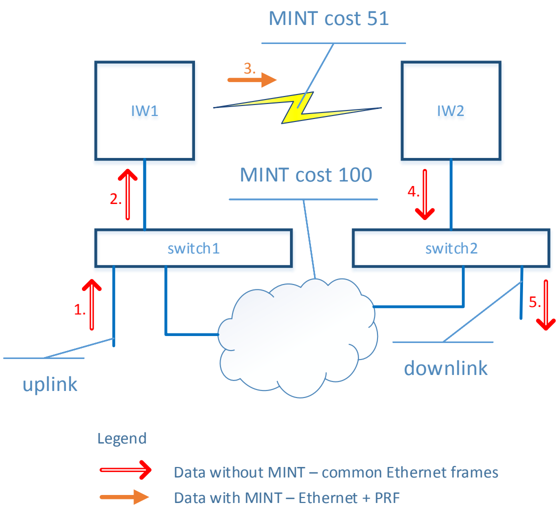


Figure 34 – Example of traffic path for the stage one

Two IW units has two paths to transfer traffic between each other: one is radio link, another (backup path) is via Ethernet. Due to initial configuration MINT cost for Ethernet path has been chosen to be higher to load the radio link.

Traffic path:

1. Data flows to switch1
2. Data flows to IW1
3. Data flows to IW2. Now by MINT protocol. Data has been encapsulated to MINT protocol
4. Data flows to switch2. MINT service headers has been removed
5. Data arrives to destination.

4.1.2. Stage Two: MINT Ethernet is main path

Arrows represents traffic path. Different color represents data with and without additional MINT information in frame headers. Numbers along with arrows represents path stage.

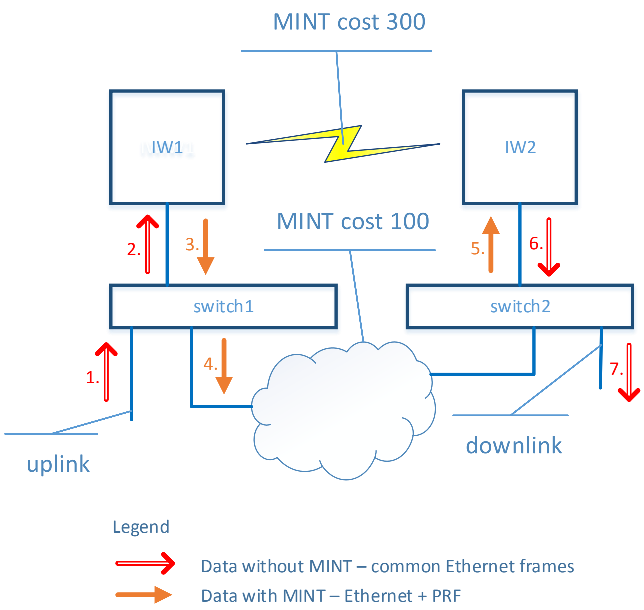


Figure 35 – Example of traffic path for the stage two

Due to some unknown reason the radio link has lost a lot in quality: right now it experience problems, mostly likely some external interference. The current bitrate is rather low and additionally there are a lot of retries (around 20 %). Therefore, the MINT adjust MINT cost for radio link, which results the MINT chose Ethernet backup path.

However, now it is interesting to see the path of traffic.

Traffic path:

1. Data flows to switch1
2. Data flows to IW1;
3. Data flows back (!) to switch1. Now by MINT protocol. Data has been encapsulated to MINT protocol
4. Data flows to switch2. MINT service headers are present
5. Data flows to IW2. MINT service headers are present
6. Data flows back to switch2. MINT service headers has been removed
7. Data arrives to destination.

4.2. Configuration part of Point-to-Point example

Steps to configure MINT-over-Ethernet.

CLI based configuration:

1. Create PRF interface

```
 R5000

 Infinet Wireless Ltd.

 www.infinetwireless.com

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 R5000 WANFleX H11S01-MINTv1.90.12 * Sep  9 2014 13:51:57 *
SN:199203



Unknown node#1> ifconfig prf0 up

prf0 link administratively up

Unknown node#1> prf 0 parent eth0

Unknown node#1>
```

2. Start MINT protocol for PRF interface

```
Unknown node#1> mint prf0 start
```

```
Unknown node#1>
```

3. Connect another MINT with PRF enabled and check connection

```
Unknown node#2> mint prf0 map det

============================================================

Interface prf0  (parent eth0)

Node  000435030AD8  "Unknown node", Id 00000, NetId 0,
(Master)

 1 Active neighbors:

---------------------

Id   Name         Node    Level  Bitrate Retry  Err  Options
--- ----------  -------- rx/tx   rx/tx  rx/tx  ---  -------

00000 Unknown node  00435130A25 0/0       0/0    0/0     0/0     prf

         load <0/0>, pps <0/0>, cost 51, H11v1.90.14

--- -----------  -------- -----   -----  -----  ---  ------

Total nodes in area: 2

Unknown node#2>
```

4. Full list of all available MINT connections

```
Unknown node#2> mint map det

============================================================

Interface rf5.0

Node  000435130AD8  "Unknown node", Id 00000, NetId 0, (Master)(pollqos)

Freq 6140, Band 20, Sid 10101010, autoBitrate 130000 (min 13000), Noise -103

 1 Active neighbors:

 -------------------

 Id      Name         Node    Level  Bitrate Retry  Err Options

---- ----------  -------- rx/tx   rx/tx   rx/tx  --- ------

00000 Unknown node   000435230A25 26/26    130/130  0/0      0/0  /S/
```

```
      dist 2, load <5/2>, pps <4/0>, cost 51, IP=10.10.10.1
      txpwr <0/0>, H11v1.90.14
---- -----------  -------- -----   -----  -----  ---  -----
Total nodes in area: 2
===========================================================
Interface prf0  (parent eth0)
Node  000435030AD8  "Unknown node", Id 00000, NetId 0, (Master)
 1 Active neighbors:
 ---------------------
Id       Name        Node    Level  Bitrate Retry  Err Options
---- -------------  ------- rx/tx   rx/tx  rx/tx  ---  ----
00000 Unknown node    000435130A25  0/0      0/0    0/0     0/0    prf
     load <0/0>, pps <0/0>, cost 51, H11v1.90.14
---- -------------  -------- -----   -----  ----  ---  ----
Total nodes in area: 2
```

Right now we have created and enabled radio link and backup MINT-over-Ethernet paths. Meanwhile, the MINT cost doesn’t differs between connections.

The answer is simple: **MINT cost is fixed and equals 51 for stub paths**.

In reality we have just created and enabled TWO independent instances of MINT protocol.

One instance operates on radio interface only:

```
Unknown node#1> config show mint | grep rf5.0
mint rf5.0 -name "Unknown node"
mint rf5.0 -nodeid 00000
mint rf5.0 -type master
mint rf5.0 -mode fixed
mint rf5.0 -scrambling
```

```
mint rf5.0 -autobitrate

mint rf5.0 -minbitrate 13000

mint rf5.0 -hiamp 2 -loamp 0

mint rf5.0 -log

mint rf5.0 prof 1 -freq auto -sid 10101010 -bitr 130000 -
band 20 \

mint rf5.0 -roaming leader

mint rf5.0 -authmode public

mint rf5.0 -airupdate passive normal

mint rf5.0 -rcmdserver enabled

mint rf5.0 poll start qos

mint rf5.0 start
```

Second instance operates on wired Ethernet interface only:

```
Unknown node#1> config show mint | grep prf0

 mint prf0 -name "Unknown node"

 mint prf0 -nodeid 00000

 mint prf0 -type master

 mint prf0 -mode fixed

 mint prf0 -log

 mint prf0 -authmode public

 mint prf0 -airupdate passive normal

 mint prf0 -rcmdserver enabled

 mint prf0 start
```

Both instances are completely independent and have no information of each other, no matter they are started inside the same unit.

Therefore, next step is to join these instances together:

5. Make unified MINT interface by join command

```
Unknown node#1> mint join prf0 rf5.0

Unknown node#1>
```

Now, all both MINT interfaces are treated by the unit as single entity, hence MINT exchange information using both legs (wireless and wired).

```
Unknown node#1> mint map det

============================================================

Interface rf5.0

Node  000435130AD8  "Unknown node", Id 00000, NetId 0, (Master)(pollqos)

Freq 6140, Band 20, Sid 10101010, autoBitrate 26000 (min 13000), Noise -103

 2 Active neighbors:

 ---------------------

Id        Name      Node      Level Bitrate Retry  Err Options

---- ----------  ---------- rx/tx  rx/tx  rx/tx  ---  -----

00000 Unknown node   000435230A25  26/47   130/26    0/0     0/0   /S/

       dist 2, load <3/2>, pps <3/0>, cost 78, IP=10.10.10.1

       txpwr <0/0>, H11v1.90.14

00000 Unknown node    000435030AD8     0/0     0/0     0/0    0/0   join

         load <15/1>, pps <6/0>, cost 3

---- ------------  ---------- -----   -----  ----- --- ----

Total nodes in area: 4

============================================================

Interface prf0  (parent eth0)

Node  000435030AD8  "Unknown node", Id 00000, NetId 0, (Master)

 2 Active neighbors:

---------------------

Id      Name      Node      Level  Bitrate Retry  Err  Options

---- --------  --------   rx/tx   rx/tx  rx/tx ---  -------
```

```
00000 Unknown node 000435130A25 0/0    0/0    0/0   0/0     prf
         load <20/1>, pps <7/0>, cost 6, H11v1.90.14
00000 Unknown node  000435130AD8 0/0   0/0    0/0   0/0     join
         load <4/8>, pps <4/2>, cost 3
---- ----------  --------- -----   -----  -----  ---  ------
Total nodes in area: 4
```

Each link now has its own MINT cost, which can be adjusted very quickly (1-10 ms) in case of any important link parameter change.

MINT cost for PRF links by default equals 3.

It is clear now the overall MINT cost of Ethernet backup path is not preferred cause.

The total MINT cost of wired (PRF based connection) link is 9.

4.3. Configuration of Switch Groups

CLI based configuration:

1. Create Switch Group with appropriate ID number and add at least one interface into it. Switch group without interfaces cannot be created

```
Unknown node#1> switch group 2 add eth0 rf5.0
Unknown node#1>
```

2. Start the newly created Switch Group

```
Unknown node#1> switch group 2 start
Unknown node#1>
```

3. In case of management necessity, the SVI interface should be created

```
Unknown node#1> ifconfig svi0 up
Unknown node#1>
```

4. And then the SVI should be bonded with certain Switch Group accordingly

```
Unknown node#1> svi 0 group 2

Unknown node#1>
```

Now the Switch Group is operational. In order to switch traffic between two units, similar configuration should be at least on another unit.

4.4. Change of MINT cost

MINT cost can be changed in CLI only. There are three parameters responsible for it.

When change of MINT cost occurs it remains local for the unit and is not advertised to MINT neighbors.

extracost

Syntax: mint IFNAME –extracost XX

Sets an extra cost for all connections on this interface. The value of the parameter is added to the cost automatically calculated by MINT protocol. Value of this parameter can only be positive. Zero value disables the parameter.

```
Unknown node#1> mint prf0 -extracost 60
```

fixedcost

Syntax: mint IFNAME –fixedcost XX

This command will force all the costs for all the units connected to this unit to be fixed at the value specified in the command.

```
Unknown node#1> mint prf0 -fixedcost 100
```

joincost

Syntax: mint IFNAME –joincost XX

Sets the cost of all connections on the interface which were established by means of join (3 – by default). Zero value disables the parameter

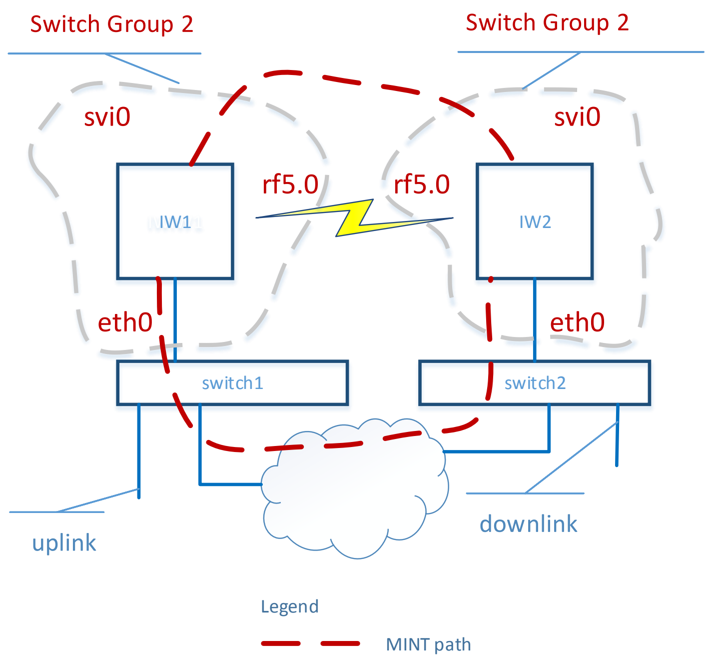
```
Unknown node#1> mint prf0 -joincost 60
```

MINT cost can be used to:

- set path priorities
- to force transmission through one leg only leaving the second leg for reception hence to simulate full-duplex behavior
- to create custom path for selected traffic only i.e. Traffic engineering.

4.5. Switching, MINT & path loops

Let's take a final look to **Example 1**, with all preceding configuration active – **mint+prf** and **switch groups**.



Now IW1 and IW2 has two connections between each other: first - through air, second - through Ethernet. Both connections powered up by MINT protocol with MINT join of rf5.0 and eth0 interfaces (please recall the MINT joint concatenates interfaces used into single logical MINT interface).

```
Unknown node#1> ifconfig prf0 up

Unknown node#1> prf 0 parent eth0

Unknown node#1> mint prf0 start

Unknown node#1> mint join prf0 rf5.0
```

Next, Switch Group 2 for both interfaces (eth0 and rf5.0) has been created.

```
Unknown node#1> switch group 2 add eth0 rf5.0

Unknown node#1> switch group 2 start
```

Switch Group creates Ethernet logical path over the MINT protocol. Since, **prf0** joined with **rf5.0** interfaces are treated as single logical interface and Switch Group 2 encompass **rf5.0** (therefore encompass **prf0**!). Thus, IW1 and IW2 now has TWO different switch path via Ethernet between each other, consequently results in Ethernet switch loop creation. It is now evident, broadcast storms would follow rapidly.

STP has to be enabled in order to prevent Ethernet switch loop.

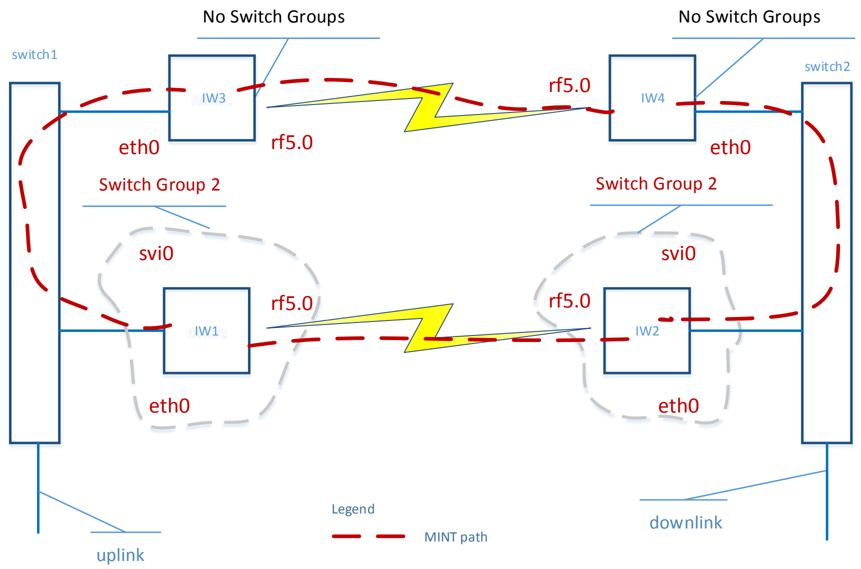
```
Unknown node#1> switch group 2 stp on

Unknown node#1>
```

Meanwhile, STP approach allows to have redundant links, but switch path would be done ONLY due to one link complete disconnect.

4.6. Switch loops and pure MINT

Better approach is to have to handle switch path selection. However, pure MINT with no Switch Group configuration is required between units, with Switch Groups configured.



IW 3 and IW4 should not have any Switch Group configuration, therefore Switch Loop won’t be created.

Thus, only units IW1 and IW2 require Switch Group configuration.

In case of Switch Group configuration on all units (IW1, IW2, IW3, IW4) the switch1 and switch2 would use both links to send data, hence Switch Loop apparently would be created.

Benefits:

- MINT can load first (IW1 and IW2) or second (IW3 and IW4) leg according to MINT cost values (bitrate, retries, load, etc.)
- Manual cost tuning will force the traffic from switch1 to use only first leg and traffic from switch2 to use only second leg, thus Transmission and Reception will be using separated increasing throughput, minimizing delay.

Drawbacks:

- Failure of the IW1 or IW2 immediately cause complete failure of data transfer, nevertheless IW3 and IW4 are ok.

Such circumstances can be easily solved by special switch with native MINT protocol support. Let's consider its benefits in next section.

4.6.1. InfiMUX introduction

The switch with MINT protocol is called InfiMUX.

The main features of InfiMUX:

- Border unit between Ethernet and MINT protocols
- Aggregation for multiple MINT units
- Load-balancer for multiple MINT links.

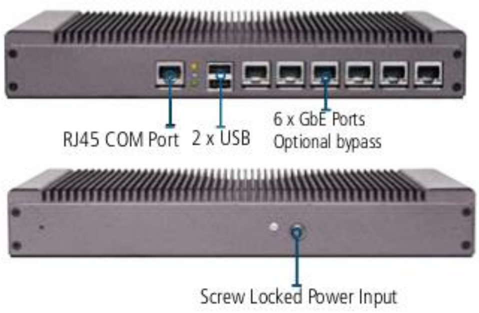
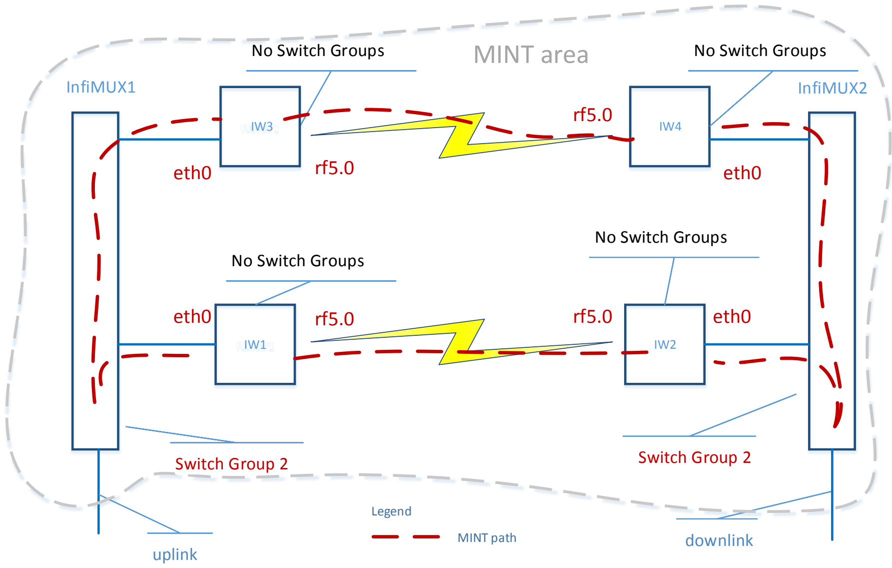


Figure 36 – InfiMUX

Each InfiMUX has 6 GE ports. Each port can have PRF configuration to work fully as MINT unit.

With InfiMUX all Switch Groups configurations reside on it. The rest IW units should have Switch Group configuration only for Management access.



InfiMUX1 and InfiMUX2 serve as demarcation units between Ethernet and MINT.

Moreover, InfiMUX units are responsible for link quality assessment and path selection using MINT. On the other hand, IW1, IW2, IW3 and IW4 should now has only basic configuration for radio link, PRF interfaces for interconnection with InfiMUX units and management switch group settings. All Switch Groups configuration for customer traffic, QoS and VLAN tags handling should be done on InfiMUX units.

4.7. Mobility example

Now, backed up with MINT introduction knowledge let's consider more advanced and mobility task.

The technical task is to ensure persistent interconnection between moving vehicles and customer network.

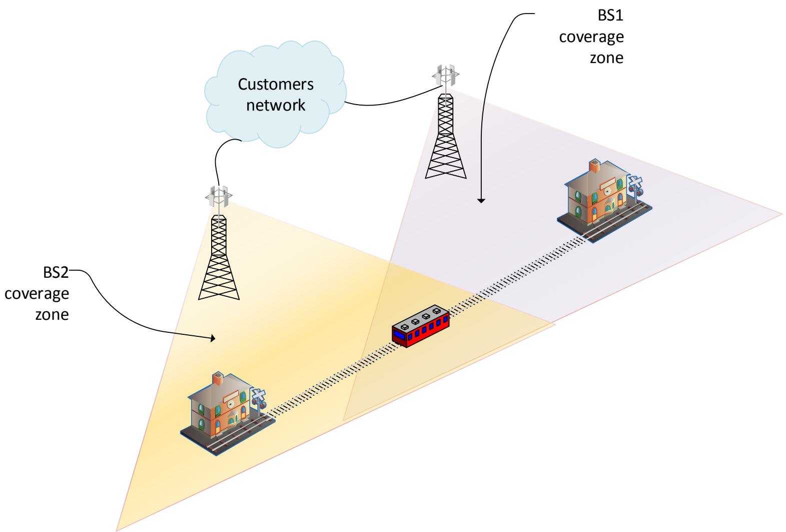


Figure 37 – Mobility example

The tasks to be solved:

- Mobile vehicle should be connected to BS with better Radio SNR
- Mobile vehicle should be able to switch between BS, without disconnects if possible
- Switch loops should not exist cause STP incur additional downtime
- Connection should be capable to transmit video surveillance data

4.7.1. Mobility example with Generic Switch

Logical scheme represent only two BS and mobile vehicle for the sake of simplicity. The same concepts and configurations could scaled to another BS and CPE's, mounted on vehicles.

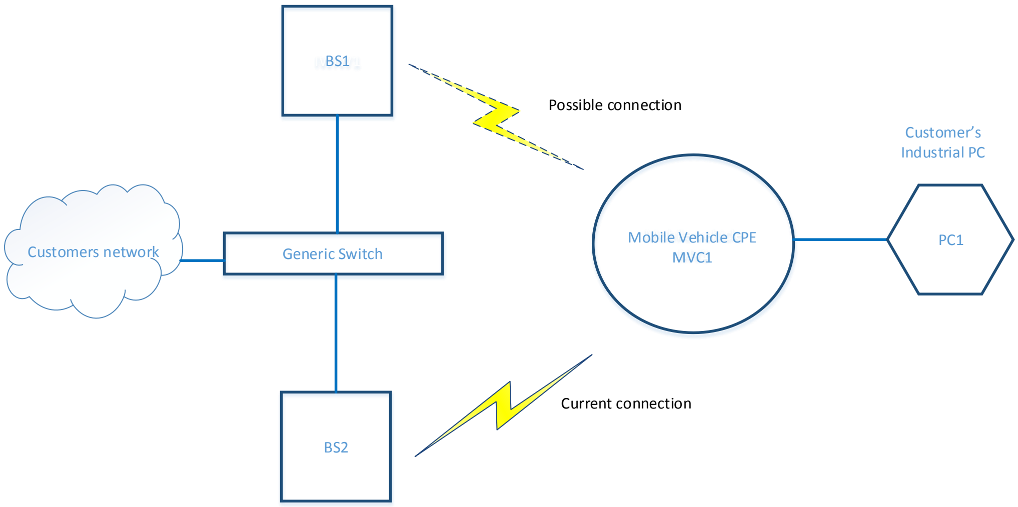


Figure 38 – Logical scheme with generic switch

BS1 and BS2 equipped by 90 sector antennas, Mobile Vehicle CPE should only operate within the radio coverage zone of BS1 or BS2. MVC1 has configured two radio profiles for connection to both BS (profiles configuration is described in ftp://ftp.infinet.ru/pub/DOC/CD_5000/MINT/English/Docs/wanflex.pdf). Generic switch is the same the customer use in their network. Mobile Vehicle has been equipped with single CPE and Omnidirectional antenna.

At first interaction, everything looks nice and sufficient. Let's check traffic flow and possible issues:

- **First stage:** Traffic flows from Customer network (CN) to PC1 through Generic Switch (GS), BS2, MVC1
- **Second stage:** MVC1 has lost connection to BS2 and reconnects to BS1:

- Traffic from CN arrives to GS
- Traffic from GS is sent to BS2, because GS still has MAC address record that PC1 MAC is available through GS port to BS2

- Traffic would be discarded by BS2, cause it doesn't have connection to MVC1
- Such behavior would be present until new Layer 2 broadcast will arrive from PC1 through MVC1, BS1 to GS. Then GS would rebuild its MAC address table for proper path
- It could take from several seconds to several minutes, everything depends on first broadcasts from PC1. So in order to fasten up the reconnection the PC1 should always keep sending keep alive frames.

- **Third stage:** MVC1 goes back and reconnect from BS1 to BS2. The downtime situation repeats until new broadcast from PC1.

CONCLUSION: Unpredictable down time with no connection from CN to PC1. Additionally, down time has two parts: first – the reconnection time of MVC1 between BS2 and BS1, second – unknown time to renews MAC address table within GS.

4.7.2. Mobility example with InfiMUX

InfiMUX based scenario:

InfiMUX should have PRF connections between all BS and thus with MVC1 through BS1 and BS2. So, common MINT network should start from InfiMUX and end at MVC1.

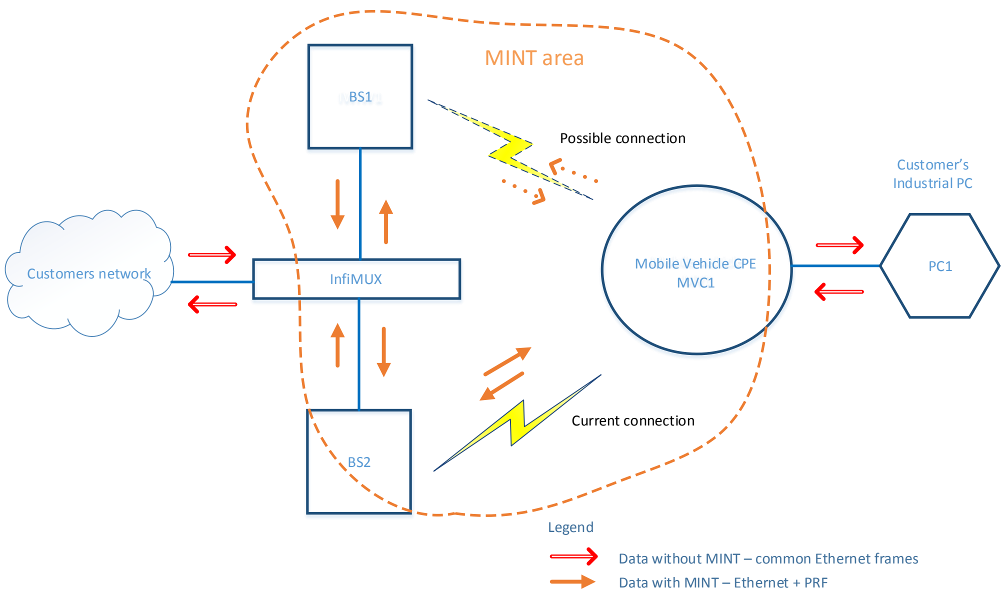


Figure 39 – Logical scheme with InfiMUX

Let's check traffic flow with MINT scenario:

- **First stage:** Traffic flows from CN to PC1 through InfiMUX, BS2, MVC1
- **Second stage:** MVC1 has lost connection to BS2 and reconnects to BS1:

- Traffic from CN arrives to InfiMUX

- Traffic flows from InfiMUX to BS1, because all MINT enabled links are constantly checked than InfiMUX always knows current connection of MVC1 to BS1
- Traffic flows from BS1 to MVC1 and afterwards to PC1

■ **Third stage:** MVC1 has lost connection to BS1 and reconnects to BS2:

- Traffic form CN arrives to InfiMUX
- Traffic flows from InfiMUX to BS2. The situation is reversed Second stage
- Traffic flows from BS2 to MVC1 and afterwards to PC1.

CONCLUSION: The downtime will be present ONLY during short re-connection period of MVC1 from BS1 to BS2 and vice versa.

In next section we will see how it is possible to almost avoid downtime periods.

4.7.3. Mobility Example. Decrease reconnect downtime. Generic Switch

In the beginning, two BS and one mobile vehicle were chosen to make the solution simple. However, in order to try to decrease or even eliminate the reconnection downtime, additional CPE can be added to mobile vehicle.

Once again, two choice would be considered. First, with generic switch, second one using InfiMUX.

So, please check logical scheme with two BS and mobile vehicle with two CPE

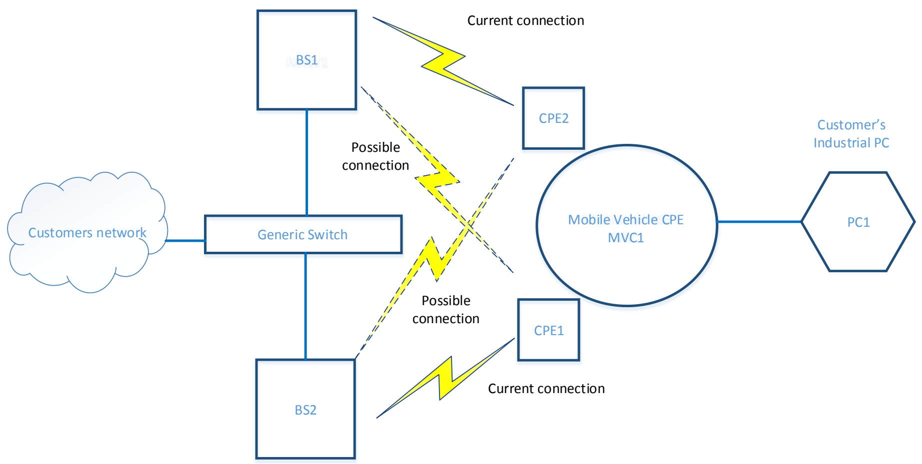


Figure 40 – Logical scheme of decrease reconnect downtime with Generic Switch

Actually, two CPE variant brings more connection choices:

■ **First choice:** BS2 connected to CPE1, BS1 connected to CPE2.

■It is evident, such connections create switch loop. Hence, STP could help to block one logical connection. Meanwhile, each reconnection of CPE2 or CPE1 would force

Spanning Tree rebuild process, which would involve GS, BS1, BS2, CPE1 and CPE2. The STP tree build could take considerable time: sometimes several seconds or even several dozen seconds. Thus, STP could bring even higher downtime between CN and PC1.

- **Second choice:** BS2 connected to CPE1, CPE2 is also connected to BS2.

Same switch loop situation is in action here too. Thus, STP impact more downtime again, than downtime due to reconnection process.

- **Third choice:** Only CPE1 or CPE2 is connected to BS1 or BS2, while the other CPE is searching for connection.

It does remind the situation with one CPE on MVC1, therefore similar consideration described in previous section with the same downtime. Meanwhile, the third choice is very rare to happen. Or it won't really impact the overall performance. In case of good radio coverage the third choice is unlikely to last long.

CONCLUSION: In case of Generic Switch usage, additional CPE would increase the downtime due to STP process operation, therefore the overall performance gets even worse.

4.7.4. Mobility Example. Decrease reconnect downtime. InfiMUX

Next, attempt to decrease downtime with InfiMUX usage.

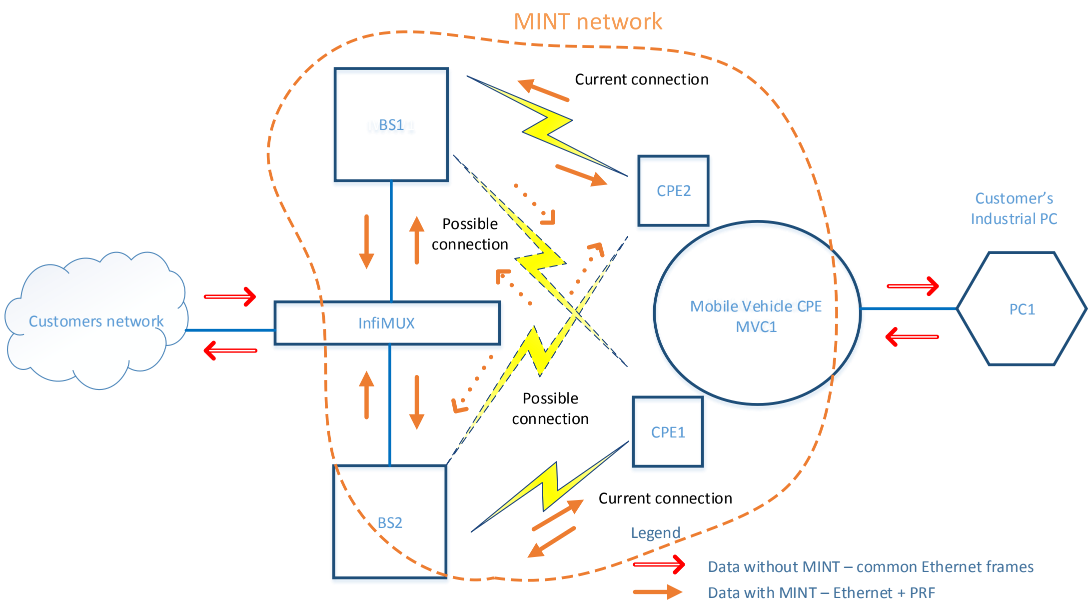


Figure 41 – Logical scheme of decrease reconnect downtime with InfiMUX

Two CPE situation again provides more connection choices:

- **First choice:** BS2 connected to CPE1, BS1 connected to CPE2

- **Second choice:** BS2 connected to CPE1, CPE2 is also connected to BS2
- **Third choice:** Only CPE1 or CPE2 is connected to BS1 or BS2, while the other CPE is searching for connection.

All these choices won't impact the traffic flow with InfiMUX in action. MINT can work with multiple routes, therefore no switch loop will occur. Moreover, the more traffic path MINT has – the traffic will be switched to the optimal and quickest path between CN and PC1.

CONCLUSION: InfiMUX shows real benefits and scalability potential with addition CPE introduction. The traffic flow cannot be interrupted logically. The downtime is unlikely to happen.

4.8. Configuration and tuning of reconnection process

4.8.1. Radio profiles operation

All IW units has possibility to switch between frequencies or even Base Stations.

Each CPE in MINT slave mode has Radio profile.

Each profile contains a fixed set of radio interface parameters, which are set on each iteration of the search. Heuristic search algorithm can quickly evaluate general air media parameters and chooses the profile, which defines the most suitable network.

Each profile has a lot of parameters. Including frequencies, sid, security keys, etc.

Each profile has all parameters required to connect to BS. Therefore, two profiles can be used for connection to two different BS.

Profile example:

```
Unknown node#1> config show mint | grep prof

Unknown node#1> mint rf5.0 prof 1 -freq auto -sid 10101010
-bitr 130000 -band 20 \

                  -nodeid 00000 -type slave -netid 0 \

                  -minbitr 13000 -autobitr -mimo greenfield
```

So, the CPE unit with 3 different profiles will be able to connect to 3 different BS.

Next, such CPE will choose BS (listed in profile) to connect with higher Signal-to-Noise ratio.

4.8.2. Re-connection between different BS. MultiBS

Another step, what happens when CPE will be disconnected from currently connected BS? By default, CPE first will try to reconnect to the same BS regardless of the link quality. In case of unsuccessful reconnects, the CPE will initiate connection to other BS, listed in profiles. For mobility project re-connection to the lost BS is not really needed, most of the time mobile vehicle will only increase distance between "old" BS and the probability of successful reconnection decrease.

The "**multiBS**" option enables the CPE to constantly check the link quality and try to find another BS, if the link quality become worse. The CPE unit with "**multiBS**" enabled can even tear down the current bad connection to BS. The decision to terminate connection depends on the signal degradation to 30-40 % in comparison to the original signal value (when connection between CPE and BS has been just established).

"**multiBS**" option is disabled by default

```
Unknown node#1> mint rf5.0 -roaming enable multiBS
```

Moreover, CPE with "multiBS" option can choose between BS.

For example, CPE-10 can connect to BS1 and to BS2. The signal quality between CPE-10 and BS1 connection is about 10-15 % better than signal quality between CPE-10 and BS2. Therefore, the connection between CPE-10 and BS1 is likely to be chosen. Meanwhile, the BS1 has 2.5 times more connected CPE count compared to BS2. Thus, the actual radio occupation time would be less provided to CPE-10 in case of connection to BS1, compared to connection to BS2, even taking into account the signal quality between CPE-10 and BS2 is lower.

When the option "multiBS" is disabled then if the link breaks the unit will firstly try to reconnect to the same BS regardless of the link quality.

4.8.3. MINT modes explained

It is possible to adjust time interval to exchange service MINT data between MINT neighbors.

It is sacrifice of throughput (cause units generate service data more frequent) to reliability. The customer can choose between either models.

MINT has three modes:

- **Fixed.** The network node has a fixed allocation and never moves and never is switched off. This is an infrastructure node of the network

MINT nodes exchanges data every 3 sec.

- **Nomadic.** Node may change its physical allocation but all the data transmitting is made when the node is not moving (or moving very slowly)

MINT nodes exchanges data every 1.5 sec.

- **Mobile.** The node may move and exchange data while moving

MINT nodes exchanges data interval is less than 1 sec.

Example below, to change mode to mobile

```
Unknown node#1> mint rf5.0 -mode mobile
```

This feature forces more frequent updates of parameters to recalculate MINT cost between MINT neighbors.

4.8.4. Decrease reconnect downtime. Wireless tuning

Meanwhile, both connection schemes with Generic Switch and with InfiMUX shares the definite downtime situation:

Fourth choice: Both CPE gets disconnected simultaneously.

So, the challenge is to try and prevent Fourth choice situation to happen.

Eventually, it is required to make CPE1 to be connected when CPE2 reconnects and vice versa, when CPE1 reconnects – CPE2 should stay connected.

MINT protocol can help in such situation too. Radio profiles configuration should be modified.

Additional helpful parameter “minbitr” should be modified.

minbitr

Syntax: mint IFNAME prof XX –minbitr XX

minbitr XXX – minimum bitrate for operation in “autobitrate” mode

```
Unknown node#1> mint rf5.0 prof 1 -minbitr 19500
```

“Mintbitr” parameter can be adjusted higher for Profile 1 – in order to force CPE to be disconnected from BS1 sooner. And “minbitr” for Profile 2 can be left intact – to keep connection to BS2 as long as possible.

Next, the radio profile configuration tuning should be reversed for CPE1 and CPE2 (radio profile 1 – for connection to

- Radio profiles for CPE1

```
Unknown node#1> config show mint | grep prof

Unknown node#1> mint rf5.0 prof 1 -freq 6100 -sid 10101010
-bitr 130000 -band 20 \

              -nodeid 00000 -type slave -netid 0 \

              -minbitr 13000 -autobitr -miso greenfield

Unknown node#1> mint rf5.0 prof 2 -freq 6200 -sid 20202020
-bitr 130000 -band 20 \

               -nodeid 00000 -type slave -netid 0 \

               -minbitr 39000 -autobitr -miso greenfield
```

- Radio profiles for CPE2

```
Unknown node#1> config show mint | grep prof

Unknown node#1> mint rf5.0 prof 1 -freq 6100 -sid 10101010
-bitr 130000 -band 20 \

          -nodeid 00000 -type slave -netid 0 \

          -minbitr 39000 -autobitr -miso greenfield

Unknown node#1> mint rf5.0 prof 2 -freq 6200 -sid 20202020
-bitr 130000 -band 20 \

           -nodeid 00000 -type slave -netid 0 \

           -minbitr 13000 -autobitr -miso greenfield
```

CONCLUSION: Let's consider the situation with such profiles configuration:

- When MVC1 will reach the edge of radio coverage of BS1 – the CPE1 will likely to keep connection to BS1, whereas CPE2 will be already disconnected (cause higher bitrate require higher SNR) and searching connection to BS2 (or probably already connected to BS2)
  - On next stage, when MVC1 is out of BS1 coverage (and already in BS2 coverage) CPE2 has been already connected to BS2 and CPE1 is waiting for connection (CPE1 will wait for better SNR to BS2 due to "minbitr" 39000)
  - Stage for back route (from BS2 to BS1) is reversed.

4.9. Mobility projects on land in general

Land projects mostly concern restricted zone to be covered. The typical projects for land mobility are: mining industry around mines and transportation roads:

- Highway routes
- Train railways
- Surveillance of closed territory
- Public transport security (with established routes).

Two major challenges to solve while dealing with land mobility projects:

Challenge	Solution
Insufficient coverage zone due to ground elevation or obstacle between BS and moving CPE	- Coverage plan should have overlapping zones - Sometimes lack of coverage can be solved by using appropriate antennas with custom radiation pattern (such shark wave antennas, for example) - More than one IW units could be mounted on moving vehicle with different antennas used (for example, one IW could have integrated directional antenna, another one – Omni antennas)
Unpredicted down time due to obstacles and re-connection between BS	- All BS should reside in one unified MINT domain (MINT-over-Ethernet) - Mobility vehicles should have more than one IW unit mounted, thus more than one active radio link would be available - All wireless MINT link could be tuned to have no packet loss, when switching from one BS to another (described in chapter "Decrease reconnect downtime. Wireless tuning")

Table 3 – Land mobility project challenges

Figure 42 – Mine example

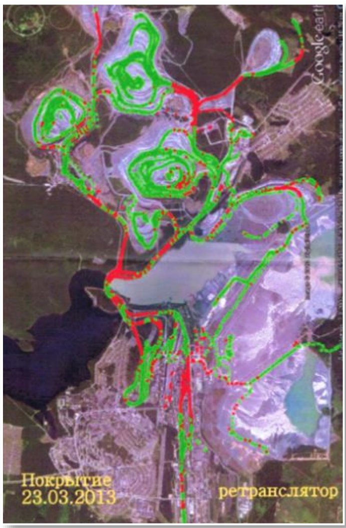
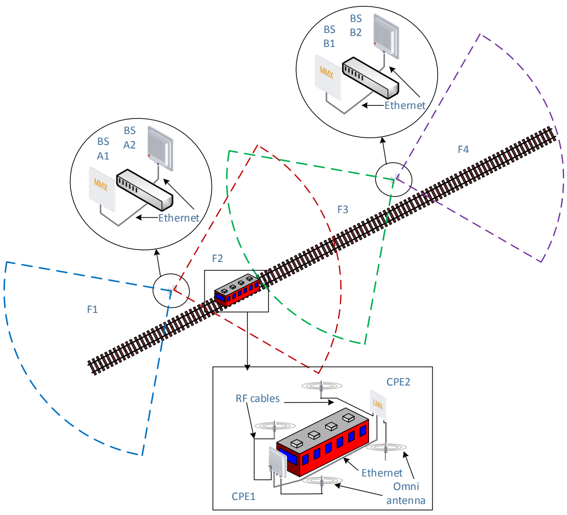


Figure 43 – Example of coverage in real mine project

4.9.1. Typical train-to-ground solution architecture



- Two BS connects back to back to each other, radio horizon of each unit aligned along the rails
- Each BS use different frequencies (F1, F2, F3 and F4) to avoid mutual interferences
- On front of each train two omni antennas mounted and connected to one CPE1
- Back face of the train (easily converted to front) also has two omni antennas connected to another CPE2
- Inter-wagon communication could use IW units as well. Two CPE easily solves such task
- Each IW unit have configuration for MINT-over-Ethernet to establish full and closed MINT area.

4.9.2. Real life example of mobility land project

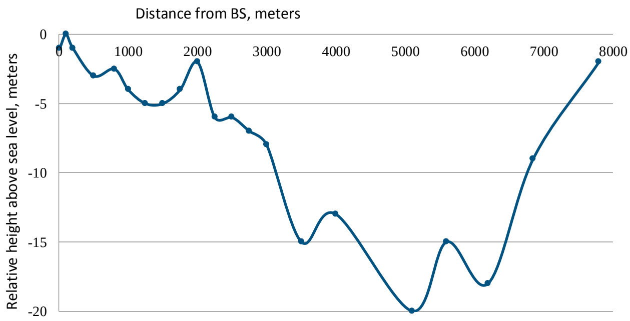
Straight-line section of the route R120 Smolensk-Bryansk in conditions of heavy traffic with partial lack of direct visibility due to heavy vehicular traffic. Local terrain features allowed to provide direct visibility up to 3 km.

BS equipped by 16 dBi dual-pol antenna was mounted on a bridge fence at a height of 10 m above the ground level and a peak of antenna pattern was directed along the highway R120

Broadcasting point was installed at direct visibility boundary in a 3 km from base station

Omni antennas were placed on the roof of the car at a height of 2 m above the road

During the tests car moved at a speed of 120 km/h



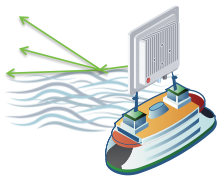
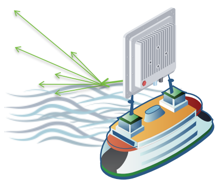
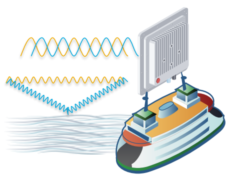
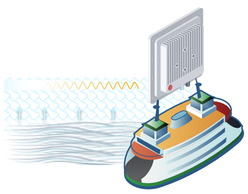
At a driving out from BS coverage zone and reaching threshold relation signal/noise in 4 dB, car automatic switched to the broad casting point. The time was less than 1 s.

At a reverse driving out from the broadcasting coverage zone, car switched back to BS when it again reached threshold relation signal/noise in 4 dB.

4.10. Sea mobility projects challenges

Unlike land projects – sea projects look very similar. Mostly they are:

- Sea ferry projects
- Offshore communication between land, oil platforms and vessels.

Challenge	Illustration	Solution
Multiple reflections Radio signal is reflected off water. Multiple signals of same transmission confuse receiver		■ TDMA based firmware should be used, cause only direct (non reflected) signal would be accepted; ■ MISO does contribute due to Antenna Diversity feature Retransmission percentage control keep low level of malformed data received
Scatter Radio signal is fragmented over water. Different parts of the transmission is received at different times, from different angles, and at different levels of power		■ Additional buffering allows to re-assemble all frames ■ Moreover, TDMA firmware drops all unsynchronized (due to scattering) data, thus eliminating self-interference
Inversion Calm water, swamps, or beach crossings result in identical signal reflections at inverse phase. Radio wave is effectively cancelled		■ Dual (or more) radio transmission/reception AND dual polarity antenna. The polarity can change on either of the transmission radios ■ All traffic flow between multiple units installed on vessel is successfully handles by MINT protocol features
Ducting Calm, warm water induces high evaporation. Cold morning air lifts humidity into atmosphere rapidly. Signal is severely faded.		■ Dual (or more) radio units should be installed on ship ■ Each radio unit should have possibility to work on different frequencies (with different BS) – Radio profile feature used ■ Since no two frequencies fade the same, having a second transmission on an alternate radio frequency eliminates this problem
Longer distances No obstacles, no elevation profile changes. However, BS can be mounted only on main land or on small island along the vessel route		■ BS on land could have integrated narrow beam antennas. PtP unit with narrow beam antenna could be turned to BS only by software license upgrade; ■ Vessel could be equipped with 2 or even 4 sector antennas to have higher gain and 360° coverage

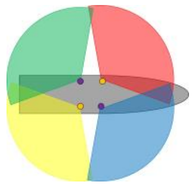
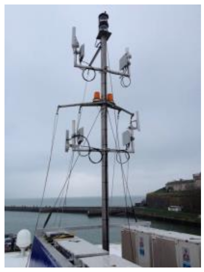
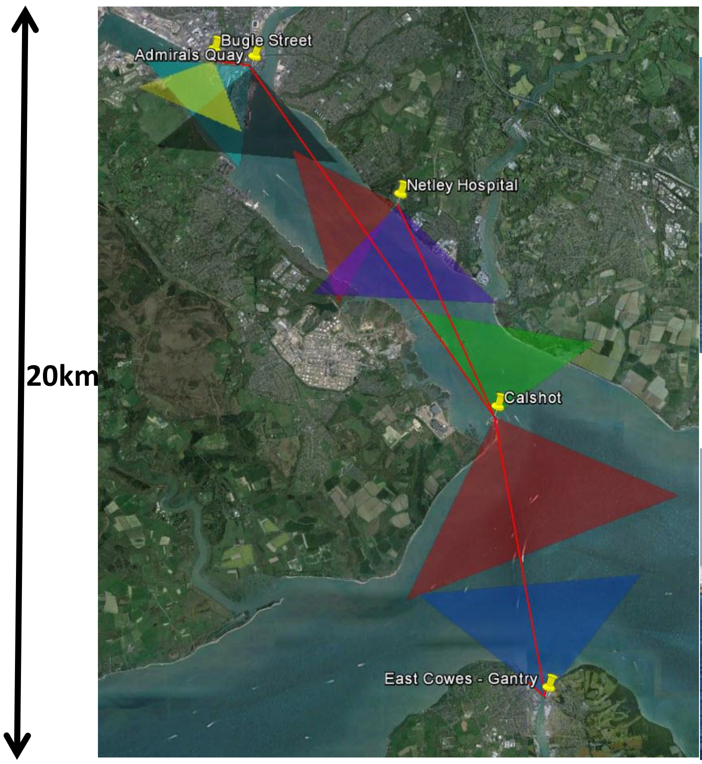
Challenge	Illustration	Solution
		4 antennas location on vessel. Each antenna has 120° coverage  

Table 4 – Sea mobility project challenges

4.10.1. Real life example of mobility sea project

- Provide wireless internet access to passengers throughout journey
- Provide connectivity throughout journey
- 20 Mbit/s full duplex throughput delivered to vessel.

5 x site, 7 x sector6 vessels



3 x Ro-Ro

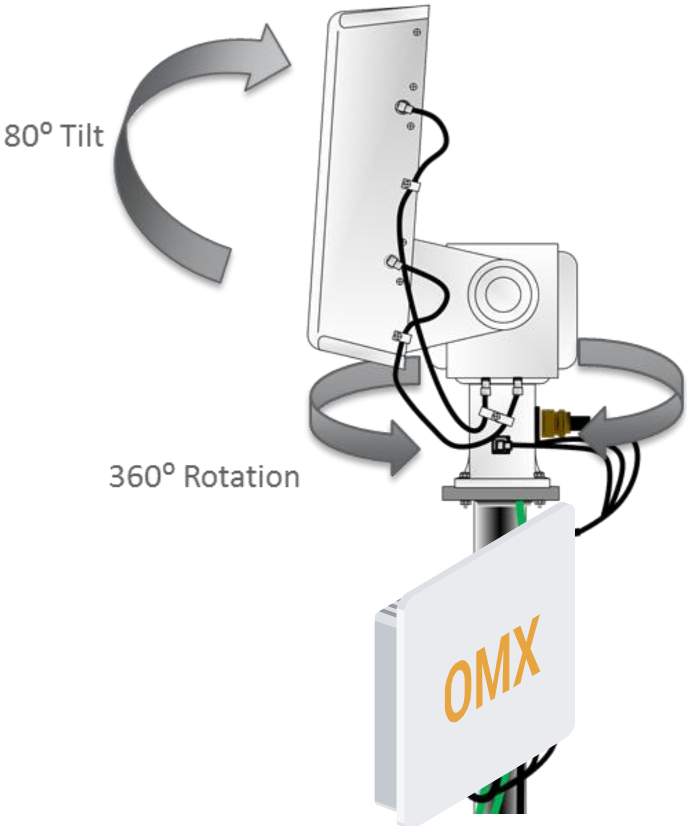
3 x High Speed

4.11. Automatic Mobile Aiming and Tracking System provided by 3rd party

Broadband Antenna Tracking Solutions (BATS), uses proprietary software and off-the-shelf electronic components that let one antenna find, lock onto and track another, even when one of them is in motion.

The system lets a seeker antenna find a target one quickly, and then constantly adjusts the seeker's position to optimize signal strength and throughput. Because BATS uses directional antennas, which focus a radio signal into a narrow beam, the connection can be maintained over longer distances and is less vulnerable to interference.

BATS Wireless provides a proprietary software and hardware platform that locates, locks, and tracks wireless broadband communication access points. BATS automatically stabilize, optimize, and tracks broadband communication links that allow improved communication distances, additional mobility to terrestrial-based communication systems, and increased bandwidth to end users.



The BATS solution comprises three main elements. One or more off-the-shelf directional antenna is packaged with the relevant radio or access point and two standard servo motors that can tilt and swivel the antenna. The motors are managed by a programmable logic controller (PLC), which in the BATS prototypes is a separate box but in the final product will likely be a small board incorporated in the antenna-radio-motors package.

The heart of the system is the software that reads the signal strength of a target antenna and then calculates the optimal position for the seeker antenna. The program passes instructions via the PLC to the servos, which move the seeker into position. If both ends of the link are stationary, the software can lock that position. If one end is mobile, the software continually tracks the target antenna and adjusts the seeker's position as needed.

Through the use of our industry-leading autonomous stabilisation and optimisation platform, BATS-enabled wireless links, can realize signal accuracy to 0.05°, and immediately counteract many of the sensitivity issues that come from misalignment of high-bandwidth microwave antennas.

Main disadvantage of such system is incredible high cost of equipment.

Conclusion and Links

Chapter 5

5.1. Conclusion

Infinet Wireless do not produce pure MESH units, however unique strong benefits of MINT protocol allows the usage of special Infrastructure MINT objects consisting from several IW units. Moreover, special configuration and tuning allows to create versatile and robust solution even with re-connection scheme without data loss.

Various antenna selection due to project details helps to satisfy different project details and implementations.

Additionally redundancy, load-balancing, fast reaction to ANY wireless (and wired) parameter change leads to resilient, no human assistance solution even for the mobile projects with really affordable cost.

Key advantages:

- **Failover –** Within Infrastructure MINT MESH units automatically select better link or even reconnects in case of link quality degradation
- **Load balancing –** possibility to load multiple redundant links simultaneously
- **Mobility –** MINT units (within coverage zone of Infrastructure MESH) can reconnect to different BS while in motion. Moreover, mobile units can have multiple MINT units in order to achieve no traffic loss reconnection between different BS
- **L2 management –** MINT protocol provides powerful tool to send and execute any command on any remote MINT unit within MINT infrastructure MESH.

Key highlights:

- Better ROI achieved through the use of wider channel sizing and unprecedented radio performance
- Seamless integration into existing infrastructures
- Huge savings on third-party networking equipment
- Extra ROI achieved through the provision of service levels agreements
- Low running costs for servicing and maintenance.

5.2. Links

Success stories

- http://infinetwireless.com/success-stories/mobile-wireless-broadband-connectivity-for-italian-railways

- http://infinetwireless.com/success-stories/kachkanarsky-ore-mining-and-processing-plant
- http://infinetwireless.com/success-stories/Technological-radio-network-of-Rosmorport-in-the-Gulf-of-Finland.

Specifications

- http://infinetwireless.com/products/infilink-2x2
- http://infinetwireless.com/products/infiman-2x2.