Network Slice Recovery with VRP

Sifat Ferdousi

October 20, 2017

Network Slicing

- One of the biggest advances in the evolution toward 5G is *network slicing*.

- A Network Slice is a managed group of subsets of resources, network functions / network virtual functions at the data, control, management / orchestration, and service planes at any given time.
  - A network slice is programmable with flexible capabilities.

- 5G network slicing "promises flexibility and allows the network to be manipulated on the fly" to accommodate different use cases.

Network Slicing

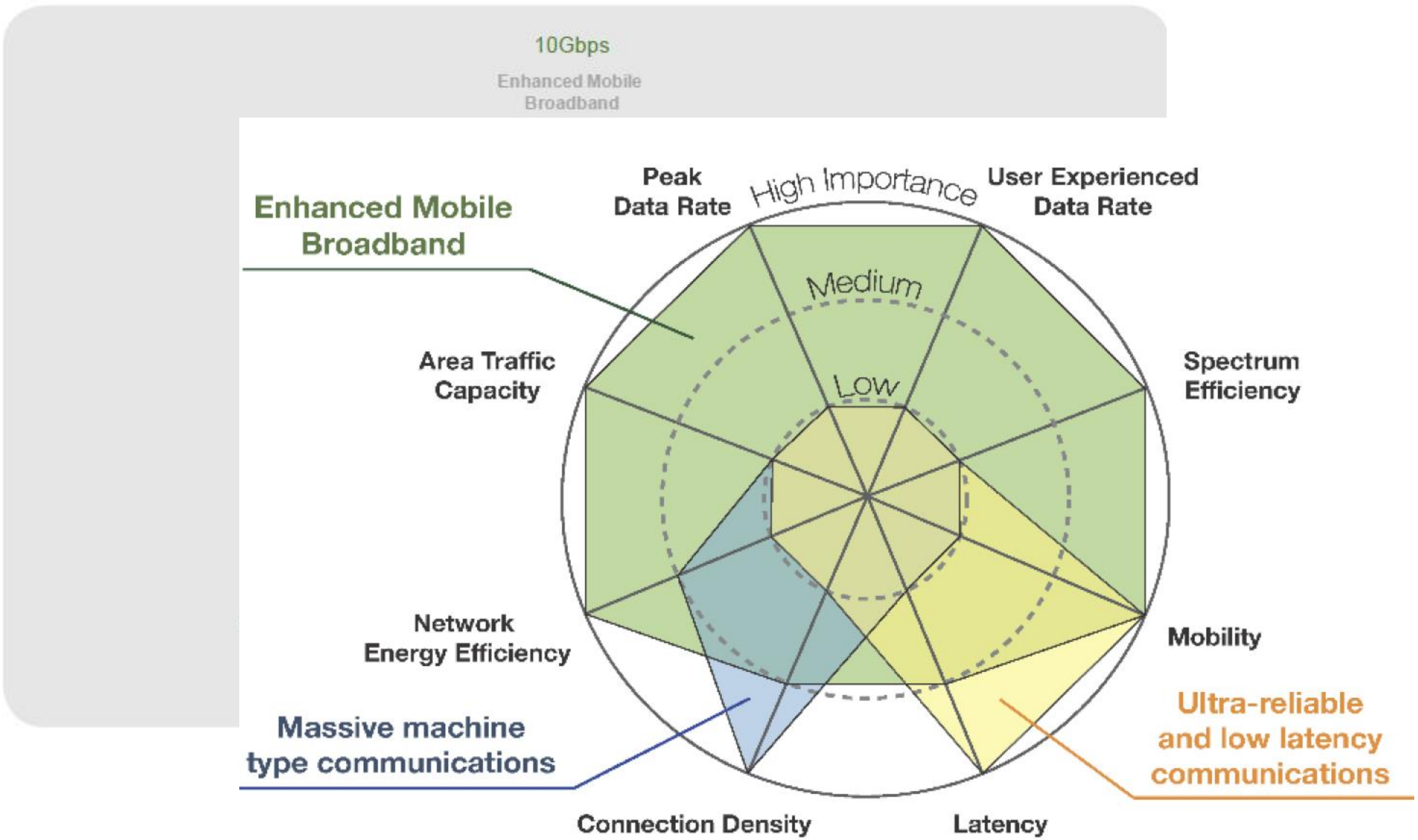
- One of the many reasons that network slices are so important is that the use cases for future 5G networks are so diverse.

- Each use case will require a different configuration and requirements in the network; each use case could require its own network slice.
  - It is inefficient and expensive to build a separate infrastructure for each service.
  - Networks will be built in a flexible way so that speed, capacity and coverage can be allocated in *logical slices* to meet the specific demands of each use case.

Slice Types

- To address the different needs of different types of machines and devices, the interface between the device and network will have several different specialized/ tailored behaviors - referred to as *slice types*.

- *Slice types* are specifically targeted for:
  - ultra-low latency and high reliability (like self-driving vehicles) (URRLC),
  - devices that don't have large batteries and need efficiency (like sensors) (MMTC),
  - ultra-high speed (eMBB) as required for 4K or immersive 3d video.


10Gbps
Enhanced Mobile
Broadband
Enhanced Mobile
Broadband
Peak
Data Rate
High Importance
User Experienced
Data Rate
Medium
Low
Area Traffic
Capacity
Spectrum
Efficiency
Network
Energy Efficiency
Mobility
Massive machine
type communications
Ultra-reliable
and low latency
communications
Connection Density
Latency

Network Slicing

- Since it would be far too expensive to allocate a complete end-to-end network to each type of slice, the network infrastructure that supports 5G (and likely 4G) will employ sharing techniques (virtualization and cloud), which allow for multiple *slice types* to co-exist without having too many multiples of the resources.

- Cloud and packet-based statistical multiplexing techniques are employed to allow the slices to use each other's resources when they are free.
  - In this manner N-network slices can be implemented with far less than N x the number of resources.

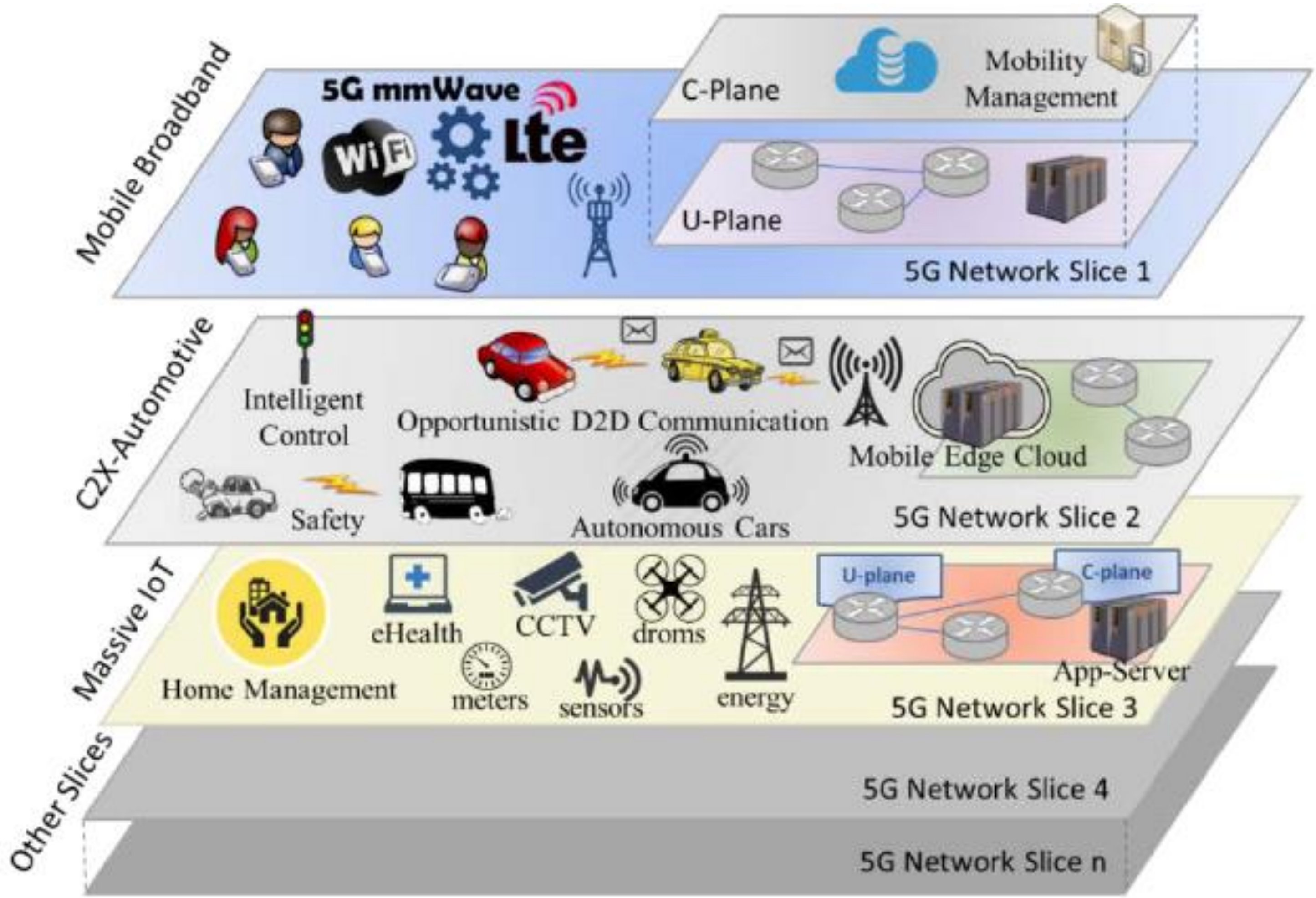
- A network slice may consist of cross-domain orchestration of services and resources over multiple administration domains –
  - It will also require interworking among operators in the network function layer or components applicable to the access network, transport network, core network, and edge networks.

Network Slicing

- Essentially, we intend to take the infrastructure resources from the spectrum, antennas and all of the backend network and equipment and use it to create multiple sub-networks with different properties.

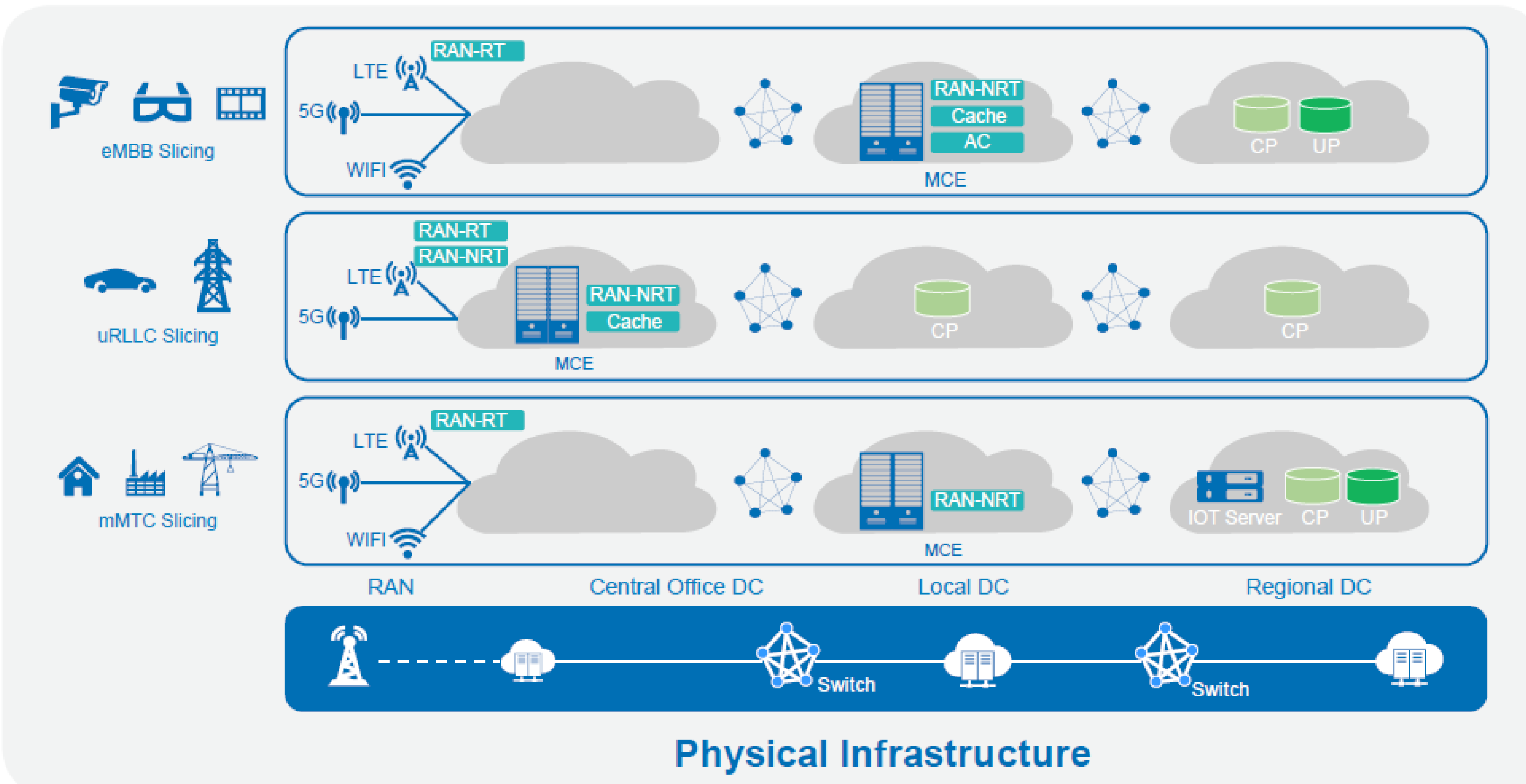
- Each sub-network *slices* the resources from the physical network, end to end, to create its own independent, no-compromise network for its preferred applications.

- Since the slices are isolated from each other in the control and user planes, the user experience of the network slice will be the same as if it was a physically separate network.

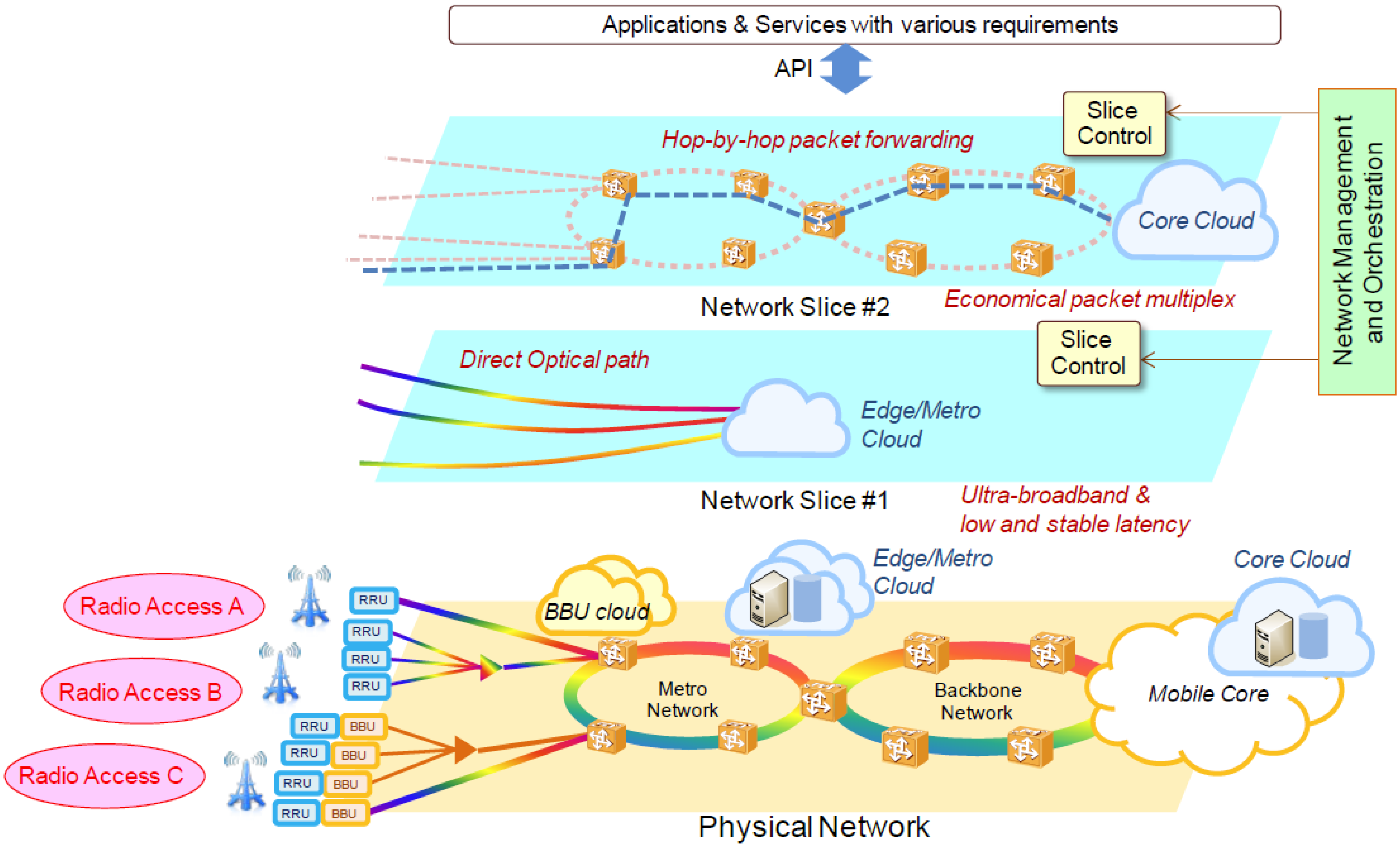


5G network slices structure

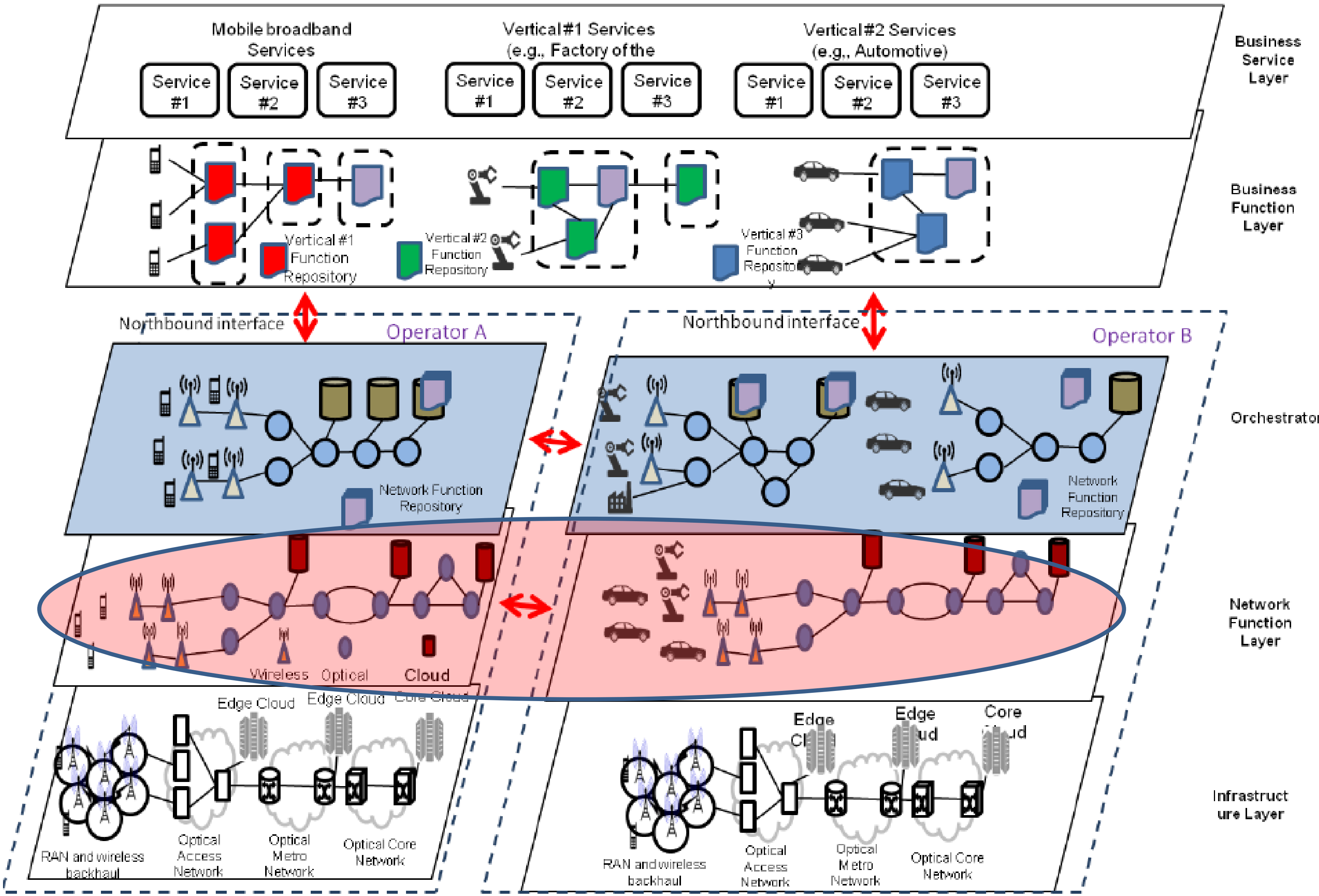
5G network slice broker NEC Germany



5G network - Huawei

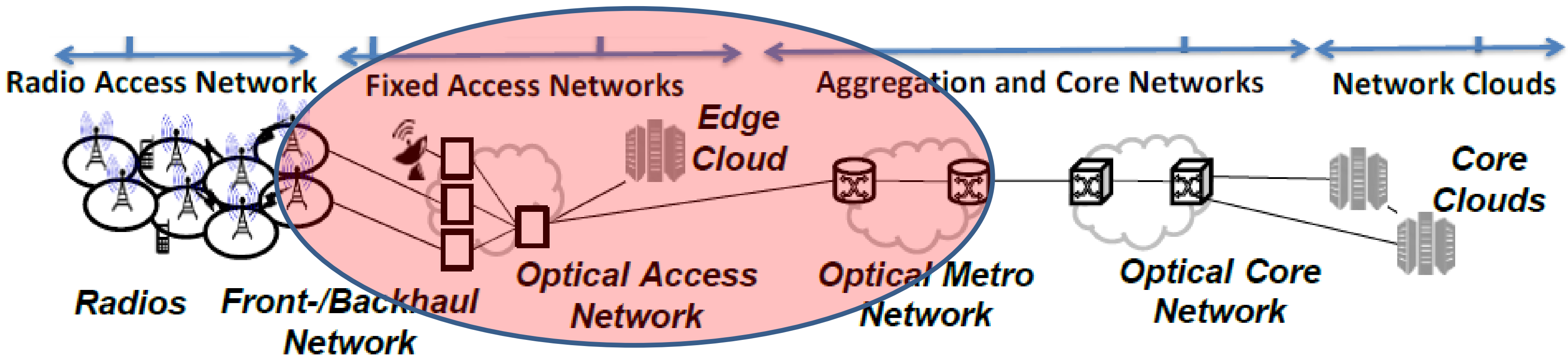


5G PPP Architecture Working Group

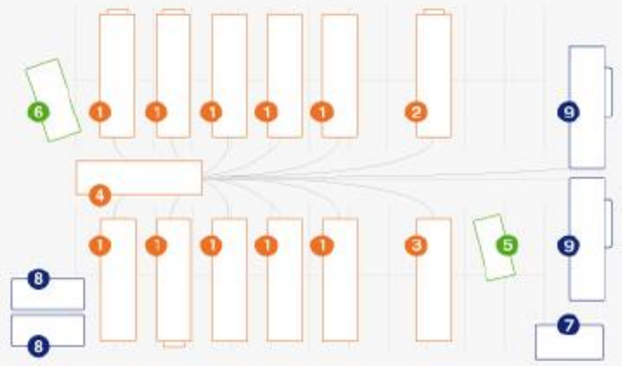


The 5G ecosystem

5G PPP Architecture Working Group


Radio Access Network
Fixed Access Networks
Aggregation and Core Networks
Network Clouds
Edge Cloud
Core Clouds
Radios
Front-/Backhaul Network
Optical Access Network
Optical Metro Network
Optical Core Network

AT&T **Network Disaster Recovery (NDR)**



95
technology recovery semi trailers
+
15
satellite COLTs* & ECVs*
+
100+
recovery team members
+
200
additional NDR equipment pieces
+
>125k
working hours devoted to recovery exercises
+
$600
million of investment

= *Rapid restoration of communications for consumers, businesses and public officials in the affected area*

1 **Technology Trailer**
Contains the same type of telecommunications equipment found in a brick-and-mortar network office.

2 **600 kW Generator**
Large portable power generator.

3 **Hardware and Machine Shop**
Carries the hardware and tools for the team to be self-sufficient in disaster-impacted areas.

4 **Power Distribution Trailer**
Acts a sub-station for the recovery site – distributing commercial or generated power to the recovery and support trailers on a recovery site.

5 **Emergency Communications Vehicle (*ECV)**
Provides satellite-based VoIP, Ethernet and Wi-Fi service.

6 **Satellite Cell On Light Truck (*COLT)**
Provides 2G, 3G, and 4G service where normal cell service is unavailable.

7 **Security Trailer**
Controls access to the recovery site.

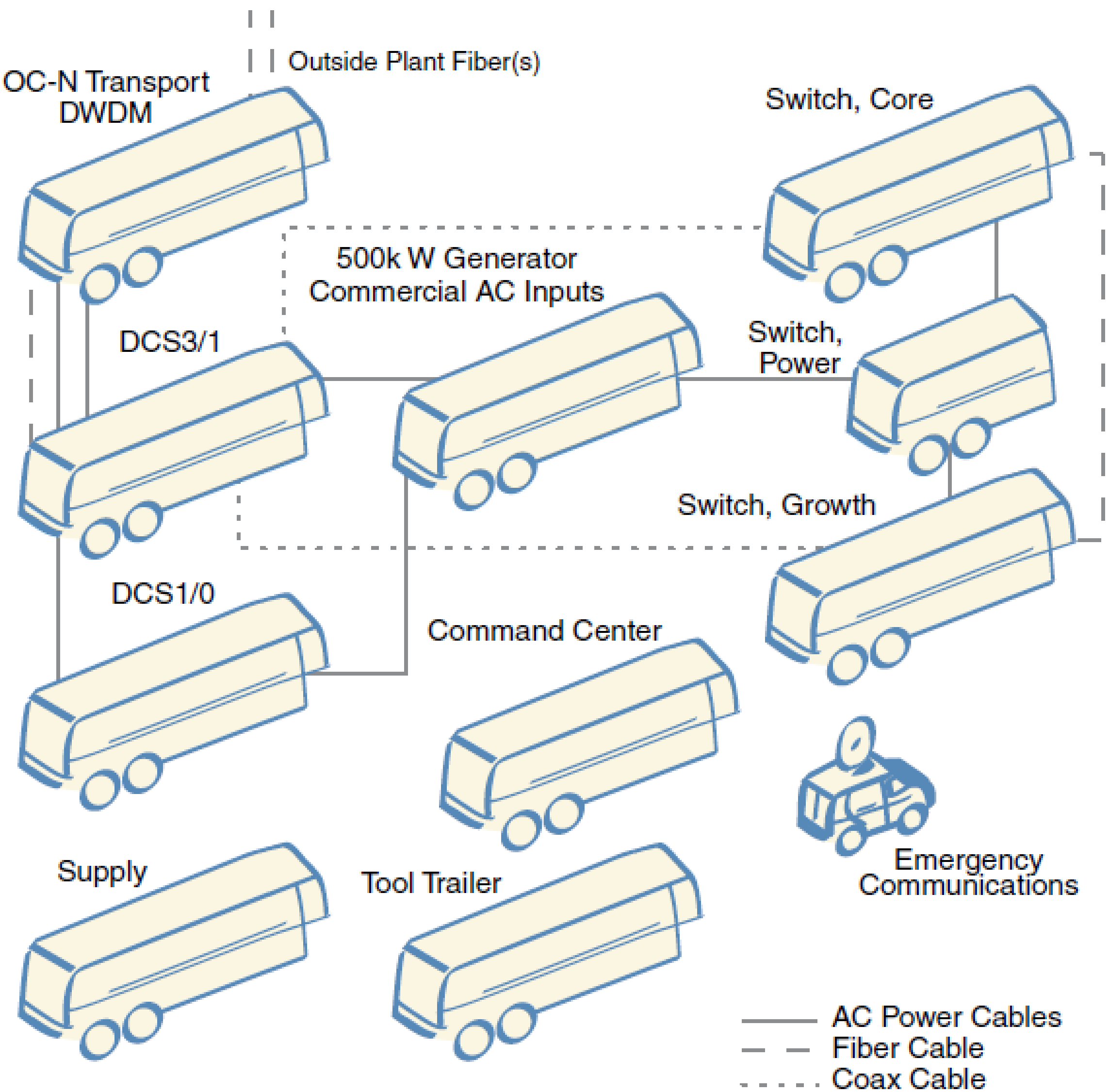
8 **Hazardous Material Response**
Houses protective hazmat suits, hazardous material meters and breathing apparatus.

9 **Command Trailer**
Provides a central command location for the recovery site and allows communications to the GNOC.

Metro Network Services, Mobile Recovery

AT&T has developed a Network Disaster Recovery capability for our Metro Network Services. Capabilities include switching and transport for DCS3/1, DCS 1/0, SONET Lightguide, and OC3/OC12/OC48/OC192 multiplexor network elements used by AT&T to provide local network services.

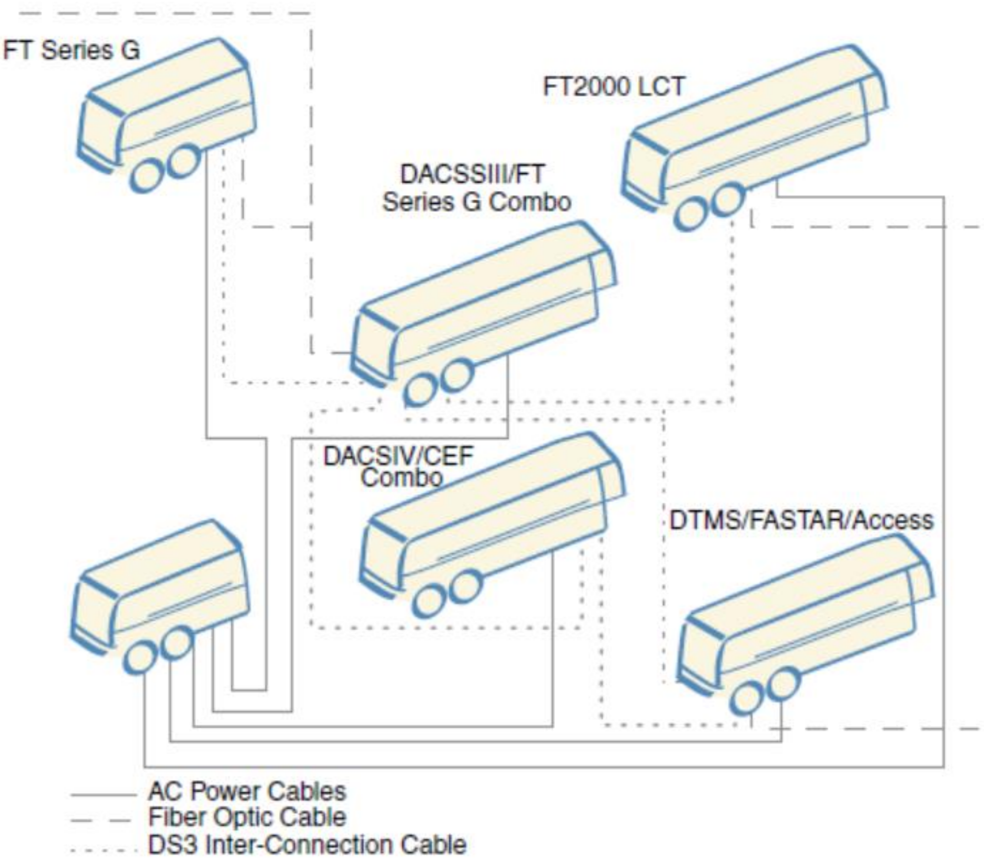
AT&T NDR has developed a trailerized solution to support optical metro deployment of MSP's (Multi-Services Platform) that connect to AT&T's DWDM backbone network.



Metro Network Services Recovery Trailer Plan, Type 1 Node

Backbone Transport Network, Mobile Recovery

All of the telecommunications equipment required to recover a destroyed or heavily damaged AT&T Central Office is transported to a recovery site in specially designed technology trailers. Each trailer has self-contained power and environmental capabilities and houses a component of the network technology that would normally be part of a permanent installation. The basic foundation of this effort is the recovery of the backbone transport network that supports the AT&T Network Services.



Backbone Transport Network Disaster Recovery


AvL
TECHNOLOGIES
at&t
att.com
FWT
at&t
USDOT 905216

- Recovering a disaster area’s cellular communications requires a functional central office and the ability to restore the capabilities provided by individual cell sites.

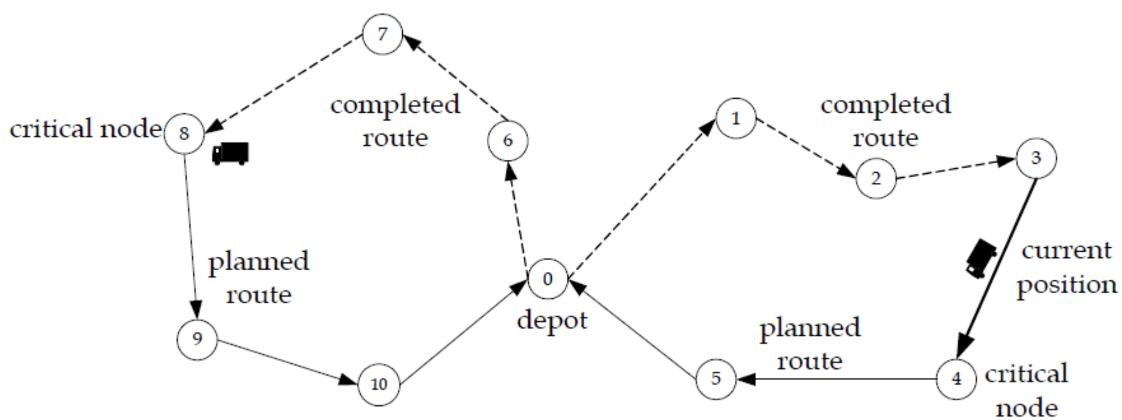
- A portable cell site — a cell on light truck (COLT) or cell on wheels (COW) — can be used to replace the service provided by a failed site. Cellular antennas are attached to a pneumatic mast on the COLT or COW and connected to the same backhaul network feed that served the permanent site.

- If backhaul facilities have also been destroyed or are not available, the data from the temporary cell site can be passed back to the AT&T network with a satellite link.

Vehicle Routing Problem

- The vehicle routing problem (VRP) is a combinatorial optimization and integer programming problem which asks "What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?"

- It generalizes the well-known travelling salesman problem (TSP).



VRP

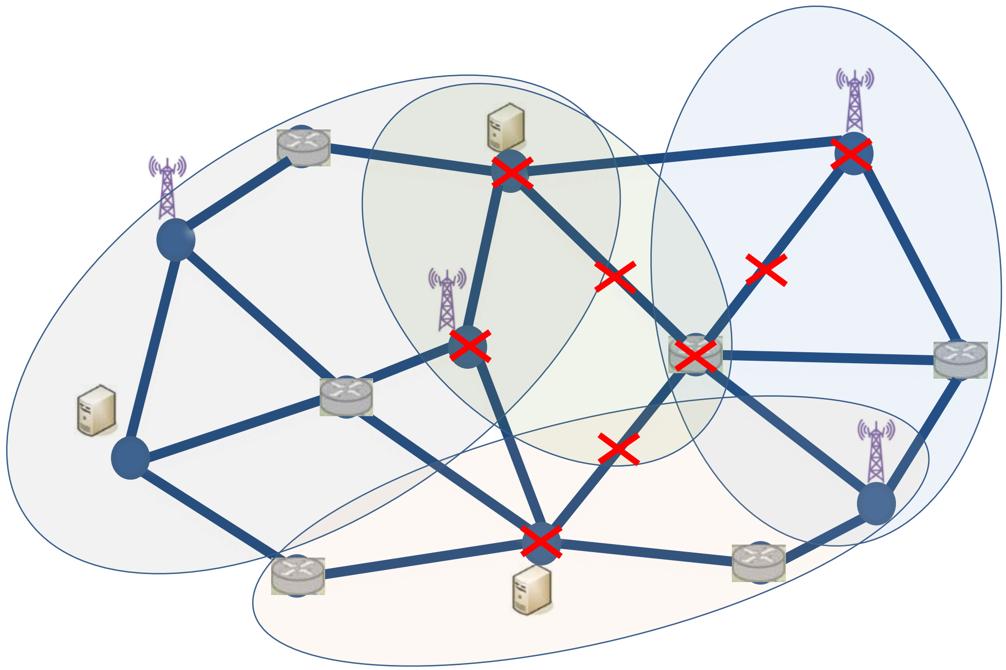
- The objective function of a VRP can be very different depending on the particular application of the result but a few of the more common objectives are:
  - Minimize the global transportation cost based on the global distance travelled as well as the fixed costs associated with the used vehicles and drivers
  - Minimize the number of vehicles needed to serve all customers
  - Least variation in travel time and vehicle load
  - Minimize penalties for low quality service

VRP variations

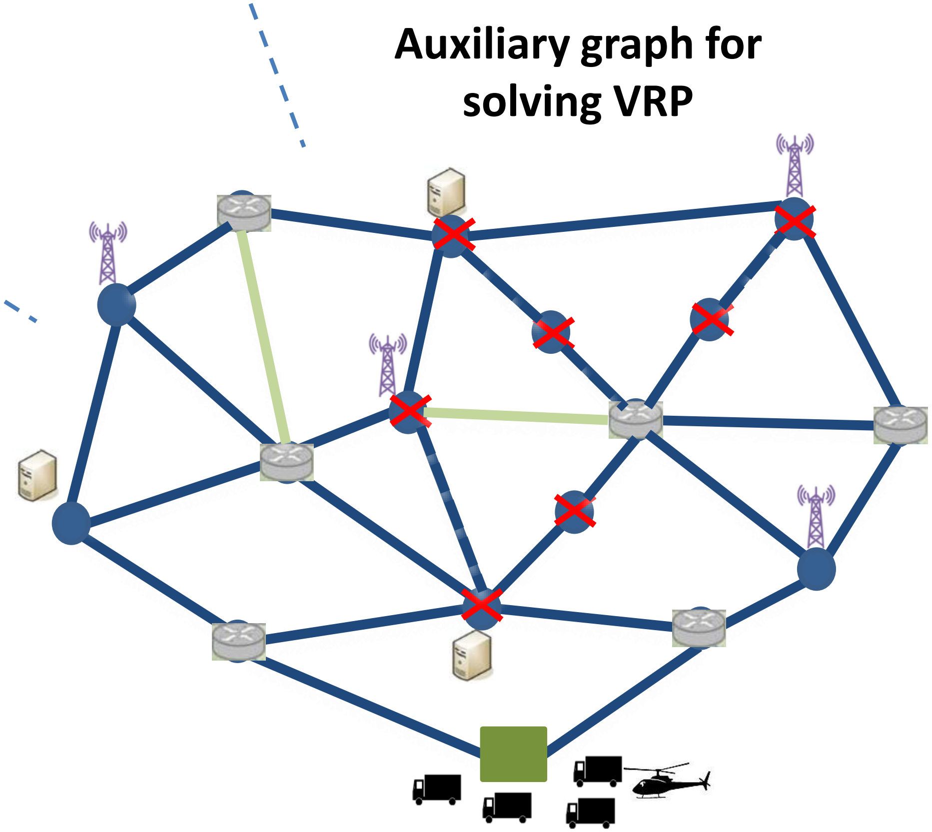
- Vehicle Routing Problem with Time Windows (**VRPTW**): The delivery locations have time windows within which the deliveries (or visits) must be made.
- Capacitated Vehicle Routing Problem (**CVRP** or **CVRPTW**): The vehicles have limited carrying capacity of the goods that must be delivered.
- Vehicle routing problem split deliveries (**VRPSD** or **VRPSDTW**): Each customer can be served by more than one vehicle.
- Vehicle Routing Problem with Multiple Trips (**VRPMT**): The vehicles can do more than one route.
- Open Vehicle Routing Problem (**OVRP**): Vehicles are not required to return to the depot.

VRP in Disaster Regions

- There had been some works on dynamic vehicle routing for relief logistics in natural disasters.
- Distribute relief goods, attend wounded people.
- Coordinated and orderly delivery/pickup of available resources helps to mitigate property damages and save lives.



Vehicle routing should be scheduled such that penalty of service downtime of each slice is minimized



Single depot – Fleet of heterogeneous vehicles

Different types of network elements require different types of repair vehicles

Slice-aware network recovery

- Most critical goal in any network recovery: minimize service downtime!

- Objective: Minimize effective service downtime over multiple network slices by efficiently recovering physical infrastructures providing services to slices.

- Recovery – *repair* and provide *temporary services* (degraded).

- Each slice has respective penalty for downtime corresponding to the slice type.

- Downtime: Vehicle travel time + deployment time.
  - Once a recovery vehicle is deployed at a failed node, temporary service is restored (with parallel repair work) and the service terminates once the node is repaired and the vehicle leaves for new destination.

- $G(V, E)$: Physical network topology with set of all nodes, V and set of all links, E.
- $\bar{G}(\bar{V}, \bar{E})$: Post-disaster physical network topology with set of failed nodes, $\bar{V} \in V$ and set of failed links, $\bar{E} \in E$.
- S: Set of logical network slices mapped on physical network G.
- V^s: Set of physical nodes $V^s \in V$ which provide service to network slice $s \in S$.
- E^s: Set of physical links $E^s \in E$ which provide service to network slice $s \in S$.
- τ: Total number of node and recovery truck types.
- $\{0\}$: Central recovery depot.

- V^r: Set of physical nodes of type $r = 1, 2, \ldots, \tau$. $V = \{0\} \cup_{r=1}^{\tau} V^r$.
- $\bar{V}^r$: Set of failed physical nodes of type $r = 1, 2, \ldots, \tau$. $\bar{V}^r = V^r \cap \bar{V}$, $r = 1, 2, \ldots, \tau$.
- $\bar{V}^{s,r}$: Set of failed physical nodes of type $r = 1, 2, \ldots, \tau$ which provide service to slice $s \in S$. $\bar{V}^{s,r} = \bar{V}^r \cap V^s$, $r = 1, 2, \ldots, \tau$.

- F: Fleet of heterogeneous recovery trucks.
- K^r: Total number of recovery trucks of type $r = 1, 2, \ldots, \tau$. $|F| = \sum_{r=1}^{\tau} K^r$.
- $t_{i,j}^{r,k}$: Travel time of recovery truck $k = 1, 2, \ldots, K^r$ between nodes $i \in V^r$ and $j \in V^r$.
- $q_i^{r,k}$: Service time of recovery truck $k = 1, 2, \ldots, K^r$ at failed node $i \in \bar{V}^r$.
- w_i^r: Required units of recovery trucks for failed node $i \in \bar{V}^r$.
- $\alpha_i^{s,r}$: Service priority of node $i \in V^{s,r}$ for slice $s \in S$.
- $P_i^{s,r}$: Penalty of service downtime for slice $s \in S$ due to set of failed nodes $\bar{V}^{s,r}$.

- $X_{i,j}^{r,k}$: 1 if node $i \in V$ is served after node $j \in V$ by recovery truck $k = 1, 2, \ldots, K^r$ of type $r = 1, 2, \ldots, \tau$, 0 otherwise.
- $y_i^{r,k}$: 1 if recovery truck $k = 1, 2, \ldots, K^r$ is deployed at failed node $i \in \bar{V}^r$, 0 otherwise.
- $a_i^{r,k}$: Arrival time of recovery truck $k = 1, 2, \ldots, K^r$ of type $r = 1, 2, \ldots, \tau$ at node $i \in V$.
- z_i^r: Effective service downtime of node $i \in \bar{V}^r$.
- P^s: Penalty of service downtime for slice $s \in S$.

$$min \sum_{s \in S} P^s \qquad (1)$$

$$\sum_{j \in V} X_{0,j}^{r,k} = 1, \qquad (2)$$

$r = 1, 2, \ldots, \tau, k = 1, 2, \ldots, K^r$

$$\sum_{i \in V} X_{i,l}^{r,k} - \sum_{j \in V} X_{l,j}^{r,k} = 0, \qquad (3)$$

$\forall l \in V, r = 1, 2, \ldots, \tau, k = 1, 2, \ldots, K^r$

$$\sum_{k=1}^{K^r} y_i^{r,k} = w_i^r, \qquad (4)$$

$\forall i \in \bar{V}^r, r = 1, 2, \ldots, \tau$

$$y_i^{r,k} \leq \sum_{j \in V} X_{i,j}^{r,k}, \qquad (5)$$

$\forall i \in \bar{V}^r, r = 1, 2, \ldots, \tau, k = 1, 2, \ldots, K^r$

$$a_j^{r,k} \geq (a_i^{r,k} + q_i^{r,k} + t_{i,j}^{r,k}) - M(1 - X_{i,j}^{r,k}), \text{if } i \in \bar{V}^r \qquad (6a)$$

$$a_j^{r,k} \geq (a_i^{r,k} + t_{i,j}^{r,k}) - M(1 - X_{i,j}^{r,k}), \text{if } i \in \bar{V}^r \qquad (6b)$$

$\forall i \in V, \forall j \in V, r = 1, 2, \ldots, \tau, k = 1, 2, \ldots, K^r$

$$z_i^r = \sum_{k=1}^{K^r} (a_i^{r,k} \cdot \frac{1}{w_i^r}), \qquad (7)$$

$\forall i \in \bar{V}^r, r = 1, 2, \ldots, \tau$

$$P^s = \sum_{r=1}^{\tau} \sum_{i \in \bar{V}^{s,r}} \left(P_i^{s,r} \cdot \alpha_i^{s,r} \cdot z_i^r \right) \qquad (8)$$

$\forall s \in S$