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On Techno-Economic Optimization of Non-Public Networks for Industrial 5G Applications

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Authors

Jyrki Penttinen
Strategic Standards Director
Syniverse Technologies
USA

Jari Collin
CTO
Telia Company
Finland

Jarkko Pellikka
Program Director
Nokia
Finland

Focus of the work

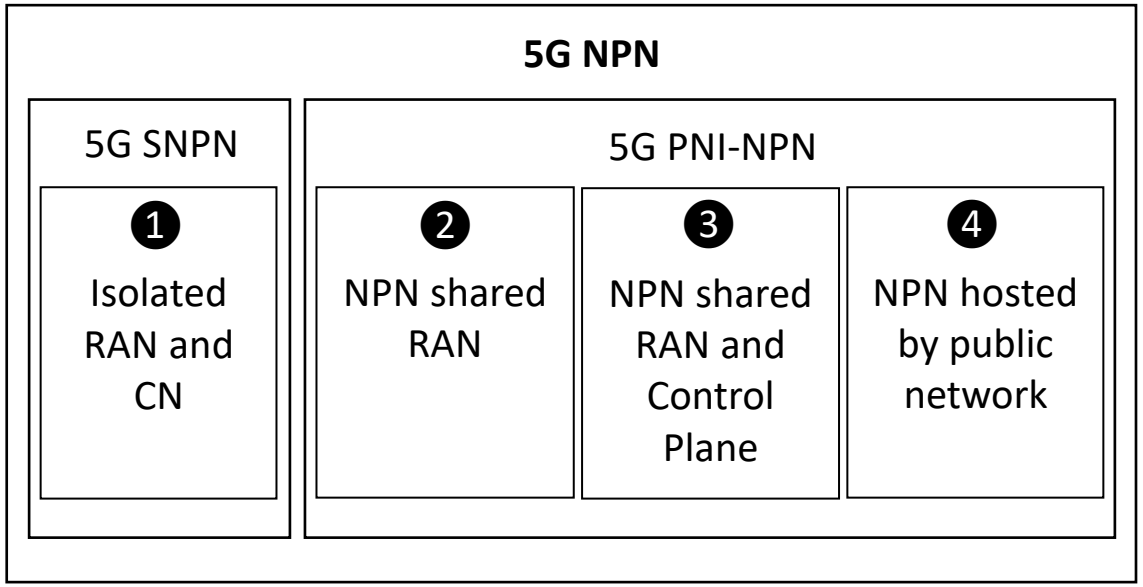
- Private Networks are gaining traction in commercial deployments as they provide benefits to many verticals.
- Among other wireless private network solutions, also the 3rd Generation Partnership Project (3GPP) provides deployment options based on mobile communication technologies.
- This study explored the current state of the art of the standardized PN solutions focusing on Fifth Generation of mobile communications (5G) and evaluated their applicability to industrial applications.
- The study presents observations on the ecosystem's needs and respective gaps in the models considering selected industrial use.
- This work also evaluated techno-economic aspects considering some of the key attributes of the available 5G deployment options and proposes a model for entities to assess the feasibility of these variants in their special environments.

The principle of private networks

- A private network (PN), referred also to as Non-Public Network (NPN), provides network services in an isolated environment.
- The PN can base on cellular networks or other wireless technologies, and its internal communications does not need to depend on numbering principles of regulated Public Land Mobile Networks (PLMN).
- The 5G Service Based Architecture (SBA) and Network Functions Virtualization (NFV) provide possibility to run the NFs on cloud, including in outsourced data center environment. This flexibility can optimize the deployment efforts and costs for setting up and operating the radio and core segments of an PN.
- The 5G NPN can be external (hosted) or reside partially (integrated) or completely (standalone) within logical boundaries of an organization using it in, e.g., enterprise, factory, or campus area, so that an entity separate from a Mobile Network Operator (MNO) assumes the responsibilities of the isolated part offering its services to a limited group.
- Due to the nature of PN, it does not typically serve inbound roamers, although its users may have outbound roaming capabilities to use other PLMNs.
- PN can include voice service in defined geographical area, or it can focus on data/IoT.
- There is a tradeoff of the level of PN ownership and its cost, level of Quality of Service (QoS), control and protection.

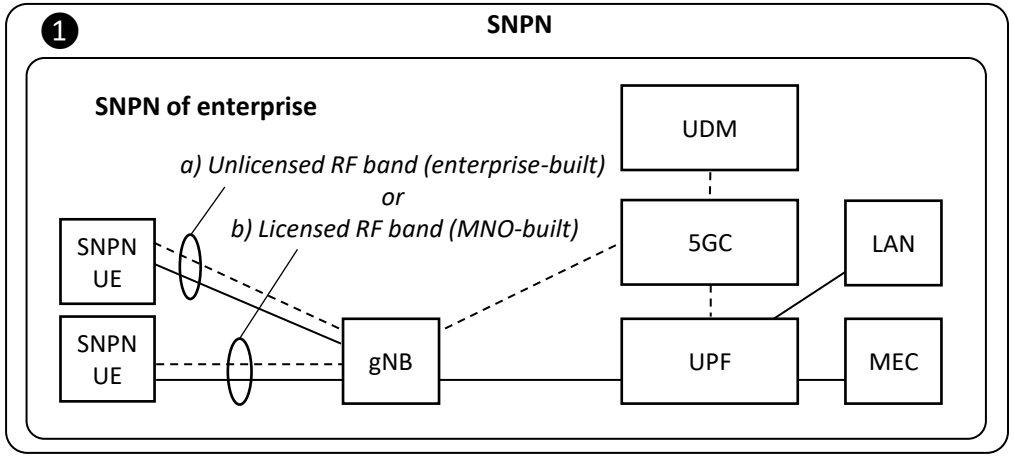
Standardization of 5G NPN

- According to the 3GPP Release 16 definitions, an NPN enables deployment of 5G System (5GS) for private use.
- The 5G NPN can be deployed as a **Stand-alone Non-Public Network** (SNPN) or **Public Network Integrated NPN** (PNI-NPN).
- An NPN operator manages SNPN without relying on the functions of a PLMN, whereas PNI-NPN deployment depends on – and benefits from – those.
- The 3GPP Technical Specifications (TS) define the arcitectures and needed functionality of the NPN, including the subscription identification.



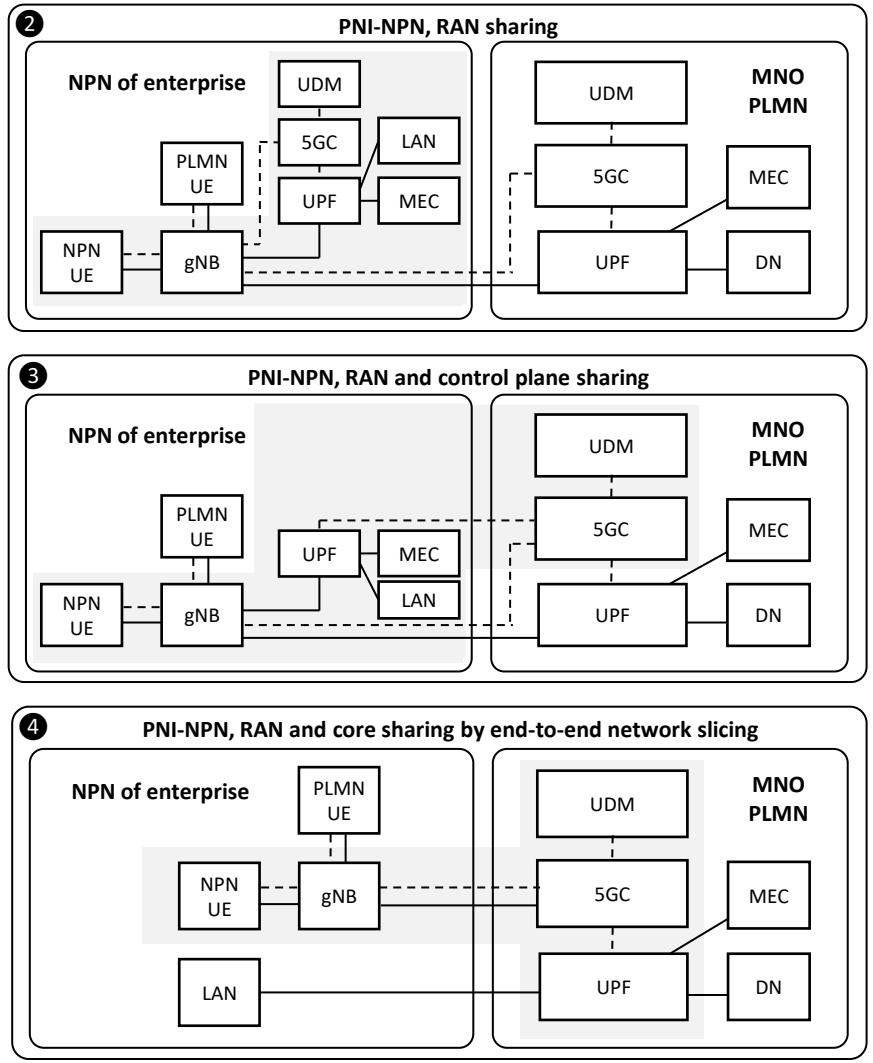
SNPN

- The Standalone NPN is separated from the public network and all network functions reside inside the organization's premises.
- The possible communication between the NPN and the public network takes place via a firewall, e.g., through Non-3GPP Interworking Function (N3IWF).
- The SNPN uses combined PLMN Identifier (PLMN ID) and Network Identifier (NID).
- 5G User Equipment (UE) supporting SNPN can attach to it based on 5G Subscriber's Permanent Identifier (SUPI) / Concealed Identifier (SUCI) and credentials provided by the network.



Shared radio access network

- In the **shared radio access network**, the NPN and public network share part of the radio access network as per the 3GPP TS 23.251 so that the communication stays within NPN.
- In **shared radio access network with control plane**, the NPN and the public network share the RAN for the defined premises while the public network handles the functions related to the network control so that the NPN traffic stays within the private network users' premises. Network slicing or 3GPP Access Point Name (APN) can realize this case.
- In **PLMN-hosted NPN**, the enterprise can be served, e.g., by a dedicated Network Slice (NS) for the enterprise users so that the MNO owns and manages the infrastructure.



Deployment aspects, SNPN

	Description	**Pros**	**Cons**
5G **SNPN**	OT operates the NPN and its services behind a firewall independently providing isolated environment to IIoT applications as data is not exposed externally. Optional PLMN interconnectivity via firewall. The operation and management of SNPN requires sufficient skillset from OT company. Provides the opportunity to build a very secure environment, but can be more expensive than only partially owned, or completely outsourced network.	• Access for customization, independent controlling; • high security by full isolation; • RAN functions are within reduced geographical area favoring low-latency applications.	• Deployment cost; • expertise required for deployment. • Dedicated network for sole enterprise includes the cost of the whole system in the geographic area.

Deployment aspects, PNI-NPN

	Description	**Pros**	**Cons**
NPN **shared RAN**	NPN and PLMN share part of the RAN, but the NPN communications stay within the defined premises. 3GPP defines well the technical RAN sharing options that can be applied in this model.	Optimizes RAN infrastructure costs while the internal data remains within the NPN infrastructure for good protection; PLMN RAN serves for delivering the data for outside of the NPN as needed. Within the NPN, part of the base stations can be connected to PLMN according to the RAN sharing agreement between the PLMN and NPN operators while the rest can be kept internal. Licensed spectrum copes interferences; deployment less expensive compared to SNPN; uses typically local functions favoring low-latency applications.	External interferences can be higher than in SNPN, and the overall control of the network is less independent; need for local expertise, although less than in SNSP.
NPN **shared RAN and CP**	NPN and PLMN share the RAN for the defined premises while the PLMN has control; the NPN traffic remains within the defined premises. 3GPP NS can be used complemented by industry forums' guidelines for slice template setup. Alternatively, APN can be used.	Licensed spectrum for controlled interferences; lower deployment expenses compared to SNPN and PNI-NPN RAN sharing; SLA can be applied between the NPN and public network.	Less independent from public networks; latency typically higher than in SNSP and PNI-NPN deployments; some local expertise required.
NPN **hosted** by public network	PLMN and NPN traffic are external to the business area so that the traffic flows are served by different networks, and the NPN subscribers are public network subscribers.	Facilitated by NSP, no need for local expertise; fast to set up and adjust based on expressed requirements. Low setup cost.	Less control for adjustments as the NS is managed by the NSP; technology not yet final; requires SA 5G that are not yet many in markets.

5G NPN types and characteristics comparison

Example of a comparison of the key differentiators

- This table summarizes typical attributes and their relative values from an **enterprise perspective**.
- Please note: the values may vary significantly in practice depending on the more specific deployment options such as the location of Edge computing and cloud resources.

For deployments comparison, CAPEX and OPEX vary depending on many factors, such as:

- Use of licensed vs. unlicensed spectrum.
- Grade of desired SLA.
- Specific values of license fees of own infrastructure / SW vs. fees of outsourced functions.

Type	Complexity	Customization	Privacy	Reliability	Latency	Expertese required	Deployment cost	Operational cost
5G SNPN	High	High	Internal	High	Low	High	High	Mid
PNI-NPN, shared RAN	High/mid	Mid	Shared	Mid	Mid	High/mid	Mid	Mid
PNI-NPN, shared RAN and CP	Mid	Mid/low	Shared	Mid	Mid/high	High/mid	Mid	Mid
NPN hosted by public network (NS)	Low	Mid/low	Outsourced	Mid/high	Mid/high	Low	Low	Low

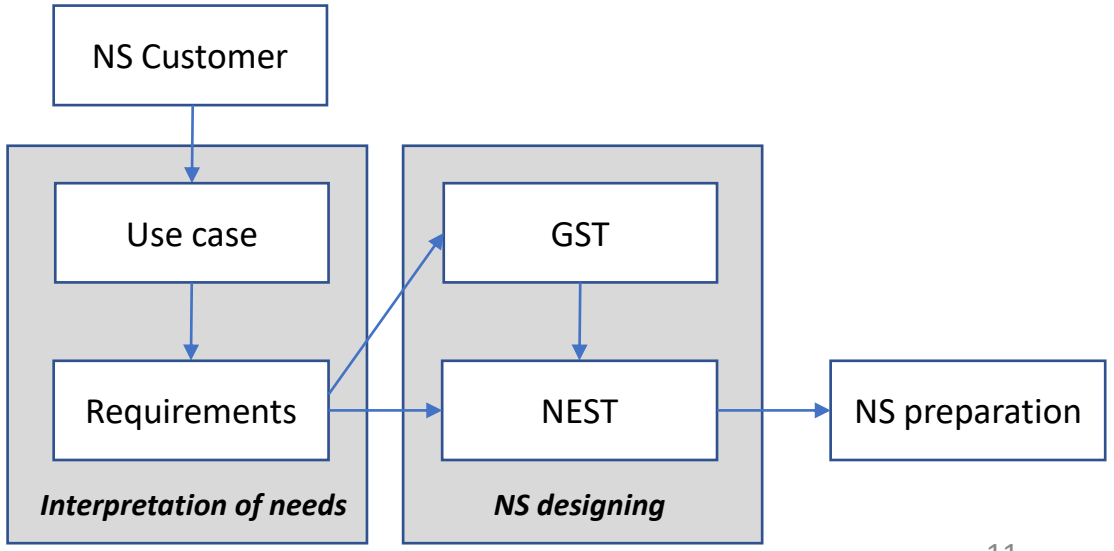
Enterprise / vertical requirements: an example of Network Slice -based PN

- Each NPN deployment model has their advantages and disadvantages.
- It is important to understand the technical needs of the verticals and their use cases.
- By assessing the requirements, and by applying tecno-economic optimization considering the key attributes and their desired value ranges, the selection of the most adequate deployment model is possible benefiting favorable business.
- The aim of the relevant requirement list is to ensure the common understanding of the environment and set the expectations also for service level amongst the stakeholders (customers and communication / service providers).

Example of an MNO-hosted PN using NS, applying the principles of the GSMA PRD NG.116.

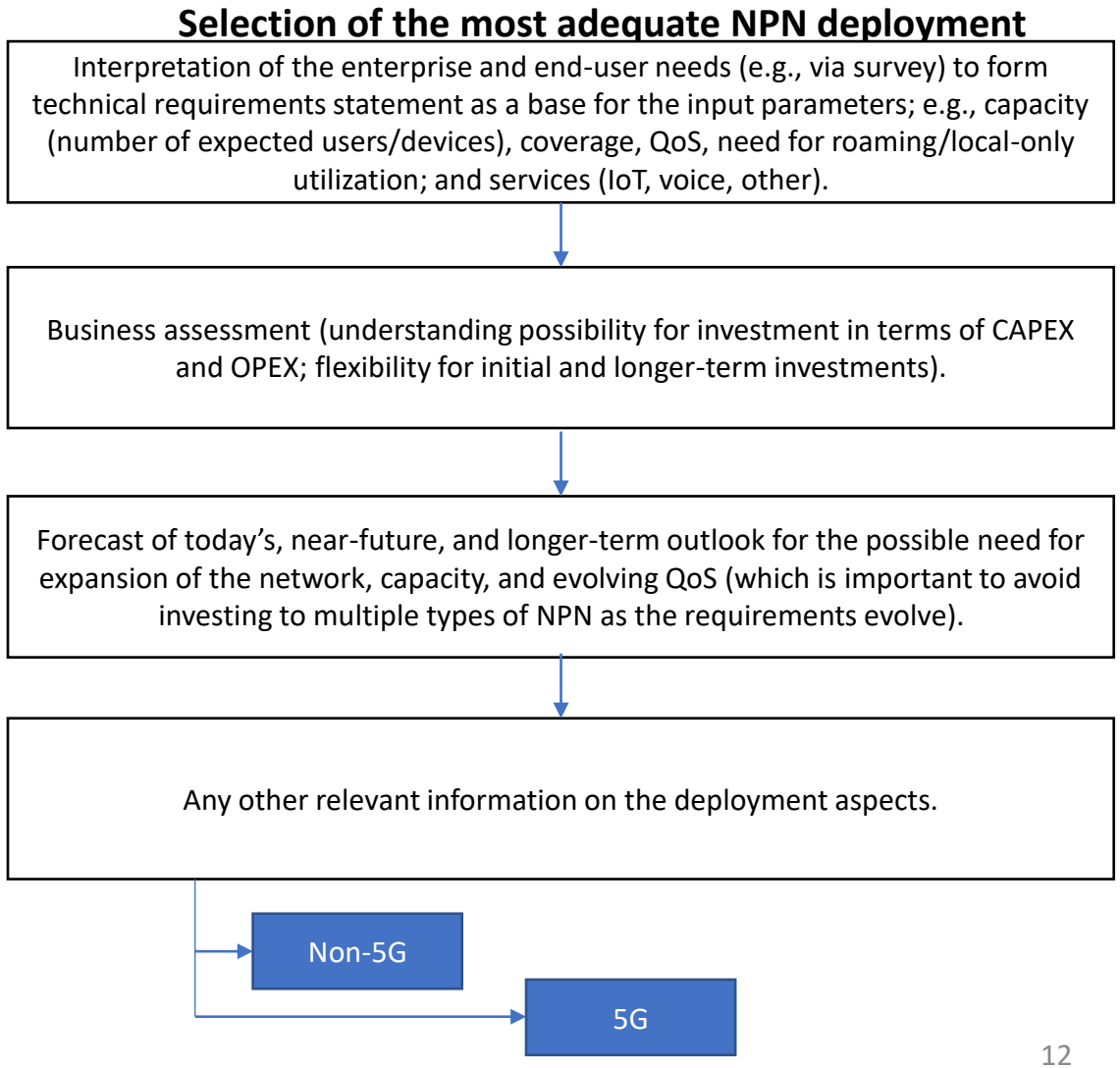
Customer needs are formed as a network slice by using:

- Generic Network Slice Template (GST): set of attributes that can characterize a type of network slice/service. It is generic, and not tied to specific network deployment.
- Network Slice Type (NEST): GST filled with values.



Enterprise / vertical requirements assessment: General process

- The techno-economic assessment considers:
  - **CAPEX** (initial deployment and estimated need for new infrastructure investments).
  - **OPEX** (yearly cost in order to operate NPN).
- In the **nominal** assessment, the CAPEX and OPEX parameters can relate merely to the most relevant and significant items.
- In a **detailed** level, the model can consider interdependencies of the items (such as volume discounts and reduced prices of bundled items) and return on investment (such as NPN service provision to external users), also as a function of time.
- The outcome indicates the costs and RoI figures per stakeholder of interest.



Proposed model for PN expense estimate

$$CAPEX = x_{gnb} + x_{tn} + x_s + x_a + x_d + x_v + x_r + \sum_{nf1}^{nfn} x_{nf} \qquad (1)$$

- Total cost of cells x_{gnb} (radio KPIs -> bandwidth, number of radio cells)[1]
- Transmission network x_{tn}
- Spectrum x_s
- Applications / services x_a
- Device number, total expense x_d
- Other variable items x_v
- Roaming and interconnectivity x_r
- Licenses to activate network functions NF x_{nf}

[1] Example: very high data rate scenario on large indoor and outdoor NPN. mm-Wave small cells, each of 80-100 m cell range, result on dozens per km^2. Part of these cells can be offered by MNO or 3rd party, and part can be taken care of the enterprise.

$$OPEX = y_m + y_{gnb} + y_{tn} + y_s + y_a + y_d + y_v + y_r + \sum_{nf1}^{nfn} y_{nf} \qquad (2)$$

The same main components as presented in CAPEX analysis generate expenses, such as licensing fees and electricity consumption, whereas an additional item to be considered in operations is the maintenance cost y_m.

Advanced business modeling

- The described modeling can be extended to estimate Return on Investment (RoI) of private network, including the business of MNO, enterprise, or 3rd party.

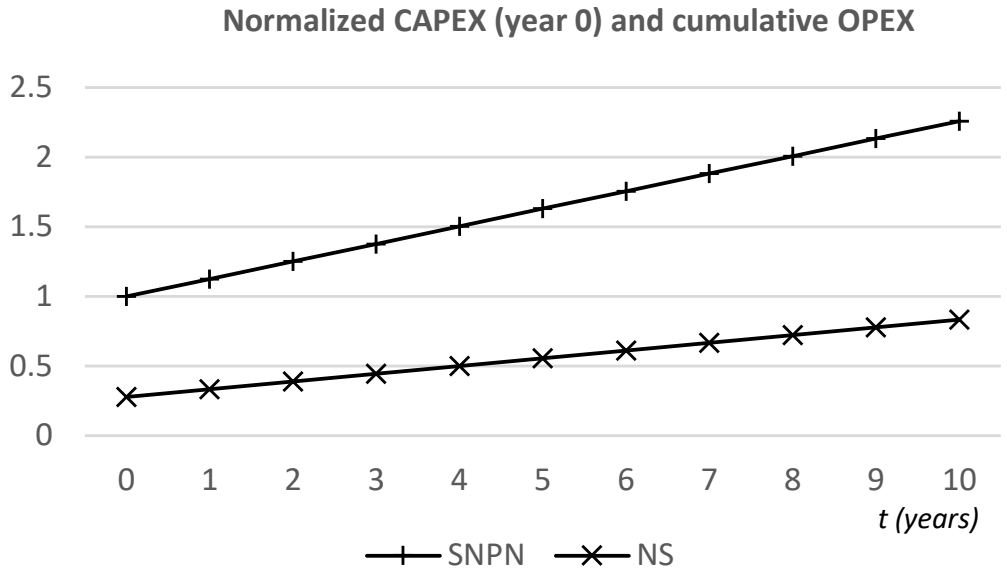
- The RoI depends on various items, such as:
  - Deployment and operational costs.
  - Share of ownership of private network components (hardware, software) versus outsourced items (e.g., 5G core that runs in virtualized environment served by cloud provider) in different deployment scenarios of interest.
  - Resulting **savings** compared to reference deployment scenario (as an example, enterprise can compare MNO-operated scenario against completely or partially enterprise-owned network).
  - Potential **earnings** for different stakeholders. As an example, enterprise managing completely or partially owned private network, either on shared or own spectrum, could allow also additional users to roam into that network for a fee that depends on the data consumption or time.

Application of the Model

- The values of the CAPEX and OPEX Equations (1, 2) depend on the markets, vendor pricing strategies, competitive landscape, and many more variables that are not available in this study. Nevertheless, to test the modeling, the scenarios can be divided into following categories considering network that:
  - is completely owned, partially owned, or completely outsourced ownership;
  - uses licensed, shared, or unlicensed spectrum;
  - has no roaming (completely isolated), or has inbound roaming, outbound roaming, or bilateral roaming.
- Additional criteria can be assessed, too, assess the suitability of the network models based on, e.g.:
  - Security / level of isolation of the network architecture;
  - Quality of Service (QoS) and Quality of Experience (QoE);
  - Latency / responsiveness time;
  - Maximum and average data rate;
  - Reliability, etc.
- The level of compliance of different scenarios can be compared by using numeric values and their weights of importance.

Example of the modeling

- Enterprise desires to compare the feasibility of:
  - Isolated, 10 x gNBs 5G SNPN on unlicensed 5 GHz mm-Wave spectrum, with 5GC on cloud.
  - MNO-hosted NPN on NS dedicated to the enterprise with gNBs that are already partially deployed for PLMN users in the area complemented by new, 5 additional indoor mm-Wave small cells in the enterprise's operational premises.
- This Figure depicts an imaginary example of key expense behavior over time using the parameters of Equation 1 and 2 and certain estimated values normalized to the SNPN CAPEX reference at year 0.
- As can be seen, in this case, the initial cost of enterprise's completely own network can be considerably higher than a subscription to an MNO's NS-based PN service due to required investments on the infrastructure.
- In this scenario, also the OPEX of the SNPN cumulates faster compared to the dedicated MNO NS due to maintenance and licensing expenses of the own network.



Summary

- NPN can serve many verticals and their use cases in a more optimal way than PLMN, to cope with special requirements such as hardened security by isolation, or higher flexibility for network settings adjustment.
- Thanks to the SBA and NFV, 5G can provide more flexible and optimal PN deployment models than the previous 3GPP generations.
- Understanding how different deployment models map with the requirements, and performing techno-economic assessment, enterprises and other entities interested in providing PN services can have realistic idea on the business impact of each scenario.
- This study presents means to assess the techno-economic feasibility of NPN models and an imaginary example on the evaluation. For the model to perform adequately, insights on realistic OPEX and CAPEX values of the model's parameters are important. Feedback from NPN proof of concepts and trials serves to calibrate this modeling and helps identify and focus on the evaluation of the most essential cost items.
- The private networks are becoming reality, and they provide a functional base for many verticals and use cases to cope with special requirements. As this study shows, even a relatively simple techno-economic comparison model can support the ecosystem to better understand the differences of the business cases related to a variety of private network scenarios.