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VALUE NETWORK CONFIGURATIONS FOR SMART CITIES

Smart city services will be enabled by telecoms networks with extensive connectivity and sensing capabilities coupled with data-based applications. However, the structure of the business ecosystems responsible for deployment and operation of the infrastructure is unclear as multiple stakeholders aim for its control. Hence, there is a need to identify solutions that enable the systematic deployment of connectivity and sensors in cities whilst increasing the usage and value of such data thereby enabling city managers and stakeholders to make better-informed decisions.

This article reports on a study of the structure of possible future business ecosystems (also known as value networks) and offers an assessment of the key technical, business, and regulatory factors affecting the feasibility of the value network. A value network is a representation of the social and technical resources within/between organisations and how they are utilised. It shows the companies or individuals involved, the roles they may play and the technical services and contracts that exist between those roles. The nodes in a value network represent roles. The nodes are connected by interactions that represent economic transactions. Value networks can be represented diagrammatically.

For the purposes of this study, 5G small cells and sensors are envisaged to be installed on lampposts to provide uniform and extensive coverage to be shared amongst incumbents, mitigating Mobile Network Operator (MNO) investment, and satisfying a city's aesthetics requirements. In addition, new city-level computing resources supporting functions such as vehicle/drone traffic control, multi-domain data aggregation, etc., are envisaged. In this way, sensor data can be aggregated and commercialised, incentivising local data owners to do the same.

A number of Value Networks Configurations (VNCs) can be envisaged for the provision of smart city infrastructure. VNCs were generated by studying the business ecosystems for both the provision of connectivity services and data services. These investigations included feedback from unstructured interviews with, for example, Finnish city workers, network equipment vendors, MNOs, and small/medium enterprises. VNCs are identified by conducting: (1) stakeholder analysis, (2) identification of technical components in the technical architecture and business roles in the value network, (3) assignment of roles and components to stakeholders. This then allowed VNCs to be compared and their plausibility assessed.

The results of the study suggest that VNCs that are driven by a partnership between a city and one or more MNOs in the form of a Neutral Connectivity Operator (NCO) and a Neutral Data Operator (NDO) offer advantages over other VNCs. They can benefit from higher cost savings, enhanced market neutrality, higher incentives for local application development, and unique city / MNO offerings that emphasise each other's capabilities. However, there are business complexities associated with joint ventures and use of neutral infrastructure but it is believed that the benefits outweigh such drawbacks.

A configuration driven by a NCO can benefit from higher cost savings, due to infrastructure sharing as well as reuse of existing fibre/spectrum/hosting resources, monopoly mitigation via 26GHz service-based competition and city oversight on sensor data collection/management. In parallel, a configuration driven by a NDO can benefit from city / MNOs complementarities, including vast/valuable municipal-data together with MNOs' analytics competence and commercial/hosting resources. This configuration can aggregate larger data volumes, including municipal-data and attract suspicious data traders, given its neutrality. As a result, local application development may be incentivised via equitable stakeholder data access.

Some of these benefits can be achieved through a configuration driven by a city/international cloud provider partnership that uses unlicensed spectrum (via IEEE-based wireless technology) or locally licensed spectrum (via 3GPP-based wireless technology). With unlicensed spectrum, mobile service quality may suffer from a suboptimal handover between small and macro cells. With licensed spectrum, MNOs could minimise use of new entrant infrastructure. Also, international cloud providers, who typically provide services in addition to hosting, may hinder equitable stakeholder data access, preventing the development of competing local services. VNCs are highly sensitive to the level of city involvement, for example, including investment via local companies – utilities, for example.

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VALUE NETWORK CONFIGURATIONS FOR SMART CITIES

Smart city services will be enabled by telecoms networks with extended connectivity and sensing capabilities and data-based applications. However, the structure of the business ecosystems responsible for deployment and operation of the infrastructure is unclear as multiple stakeholders aim for its control.

Whilst the capacity of mobile networks has increased with the deployment of more and more base stations (BSs), the rollout of 5G small cells will be costly for mobile network operators (MNOs) because of the sheer number of sites needed. Sensor networks face similar challenges given the huge number of measurement points, for example, for air quality, vehicle traffic, and street safety. Moreover, the data collected is likely to be fragmented across hundreds of systems / stakeholders; open data is typically domain-specific, weakly linked, and not consistent [1]. Hence, there is a need to identify solutions that enable the systematic deployment of small cells and sensors in cities while increasing the usage and value of such data and allow city managers and stakeholders to make better-informed decisions. [2]

This article reports on a study of possible future value network configurations (VNCs) for (a) provision of small-cell connectivity and street-level data collection and (b) data commerce in a multi-domain data aggregation and trading environment. It assesses key technical, business, and regulatory factors affecting feasibility. 5G small cells and sensors are envisaged to be installed on lampposts to provide uniform and extensive coverage at 26GHz to be shared amongst incumbents, mitigating MNO investment, and satisfying city aesthetics requirements [3]. In addition, new

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Business ecosystems

Stakeholder	Assets
City	Lampposts, Fibre and power networks, Municipal data, Data centre
MNO	Spectrum licenses, Nationwide mobile network, Fibre network, Telco cloud
Fibre network operator	Fibre network
Power company	Power network
Hosting provider	Application hosting infrastructure and services
Service provider	Application, business data
Internet of Things (IoT) company	Sensor network, sensor data
Citizen	Personal data

Table 1: City stakeholders

city-level computing resources supporting functions such as vehicle/drone traffic control, multi-domain data aggregation, etc., are envisaged. This way, sensor data can be aggregated and commercialised, incentivising local data owners to do the same.

The results of the study suggest that VNCs that are driven by a partnership between a city and one or more MNOs in the form of a Neutral Connectivity Operator (NCO) and a Neutral Data Operator (NDO), whilst having technical and business complexities, offer advantages over other VNCs. They can benefit from higher cost savings, enhanced market neutrality, higher incentives for local application development, and unique city / MNO complementarities. Other types of VNC, for example a partnership between a city and an international cloud provider, whilst benefitting from a simpler business model, have drawbacks in terms of mobile connectivity and stakeholder access to data. It was also found that increased NCO-NDO integration facilitates the provision of 5G mobile edge computing and ultra reliable low latency communications (URLLC).

Method

VNCs were generated by studying the business ecosystems for both the provision of connectivity services and data services using the Value Network Analysis (VNA) method. These investigations included feedback from unstructured interviews with, for example, Finnish city employees, network equipment vendors, MNOs, and small/medium enterprises. VNCs are identified by conducting: (1) stakeholder analysis, (2) identification of technical components in the technical architecture and business roles in the value network, (3) assignment of roles and components to stakeholders, and (4) VNC comparison and plausibility check.

City stakeholders

Table 1 summarises stakeholders and their relevant assets.

Urban connectivity analysis

Business roles and technical components

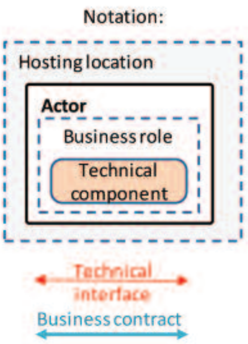
The technical components and business roles in the provision of urban connectivity are shown in Table 2.

Joint MNO-driven VNC

The city assigns the long-term exploitation

Technical components	Business roles	Description
Applications, (e.g., infotainment, smart traffic)	Service provision	Server-side applications are deployed on different hosting locations depending on requirements, as indicated by the boxes that underlay technical components.
WAN Core/Access	WAN Core/ Access provision	Core and access network functions for managing the existing nationwide MNO network, i.e. wide area network (WAN), as defined by 3GPP.
MAN Core/Access	MAN Core/ Access provision	Core and access network functions for managing the 5G lamppost network. The Metropolitan Area Network (MAN) access uses the 26GHz band.
App client, (e.g., connected vehicle)	Usage	Client-side applications are used via connected devices.
Sensors	Data collection	Privacy-sensitive sensors e.g. infra-red, 360 degrees video cameras. Non-privacy-sensitive-sensors, e.g. air quality, weather sensors.

Table 2: Business roles and technical components for urban connectivity



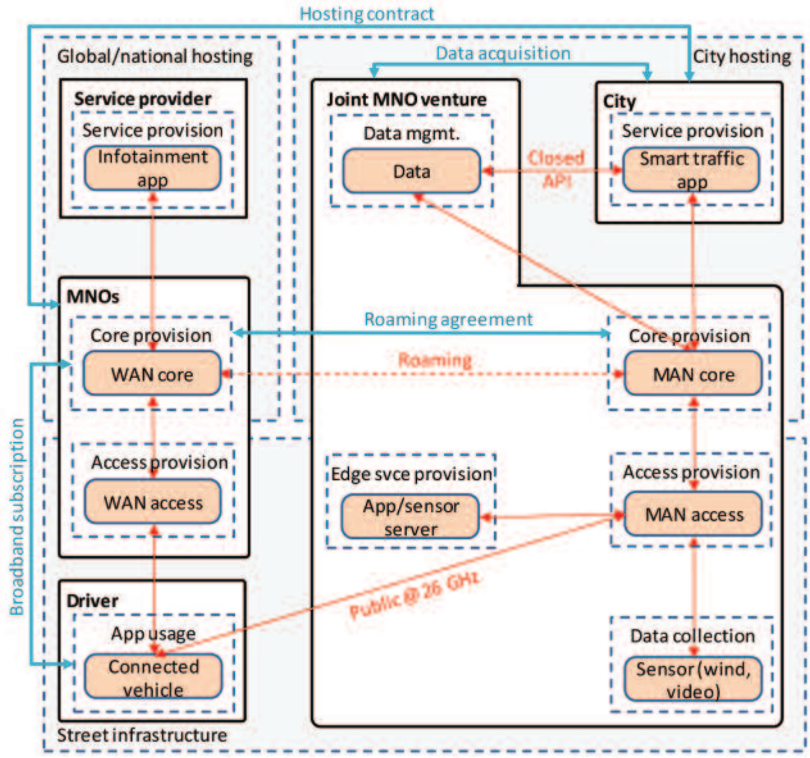


Figure 1: Joint MNO-driven VNC

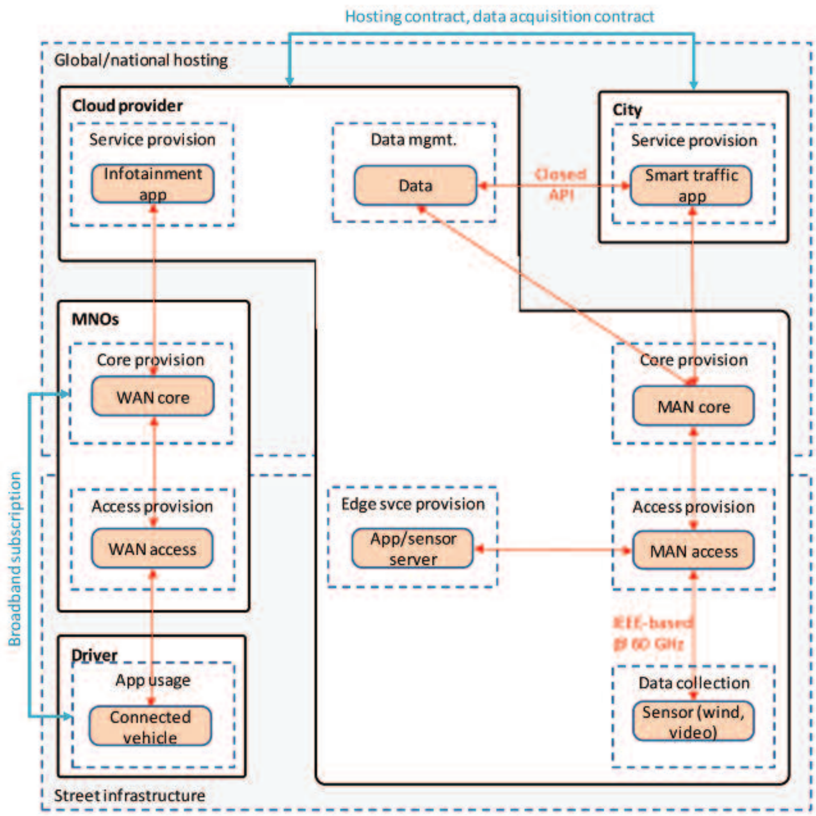


Figure 2: International cloud provider-driven VNC

rights of lampposts to a joint MNO venture, possibly enforcing minimal coverage requirements. Some joint MNO ventures already exist, including Finnish Shared Network Ltd. between Telia and DNA (an MNO in Finland), and Cornerstone Telecommunications Infrastructure Limited (CTIL) between Vodafone and O2 in the UK. While the city covers the costs of the lampposts, the venture pays for the 5G antennas, the sensors, and the civil works for connecting lampposts to existing fibre and power networks. The joint venture provides connectivity services and roams customers to existing MNO infrastructure when wide area network (WAN) access is required (i.e. a Roaming agreement is established, as shown in Figure 1). Since MNOs are likely to hold spectrum licenses in the 26GHz band, they agree to combine spectrum. Given the large volume of data collected by sensors, the venture expands existing telco cloud infrastructure which then becomes the default hosting site for city application and data (i.e. City hosting in Figure 1). In addition, the venture deploys edge hosting locations to serve application providers that require low-latency and IoT players that require local computation via 5G selective traffic routing [4]. MNOs do not allow other edge hosting locations to be reachable via selective routing.

International cloud provider-driven VNC

The city assigns the long-term exploitation rights of lampposts to a cloud provider that deploys sensors and provides IEEE-based wireless access via unlicensed spectrum (e.g. in the 5GHz, 60GHz and possibly 6GHz bands) as shown in Figure 2. A collaboration similar to this already exists between Sidewalks (a Google subsidiary) and the city of Toronto. The cloud provider cannot rely on the existing macro-cell network for device handover, which limits the service quality, albeit users could switch between networks (e.g. Google Fi). The cloud provider deploys edge hosting network in the city enabling application and data migration across Internet/city/edge data centres. In this context, Google and Microsoft have recently launched Mobile Edge Cloud and Azure Edge Zones, respectively. The cloud provider may not extend this setup to mid-sized and smaller cities due to lack of country-level resources.

Alternatively, the cloud provider could use 5G spectrum if the regulator would like to encourage investment, allowing a new player in the market, e.g. Rakuten in Japan. MNO's may react by minimizing (or even avoiding) the usage of the small-cell networks, increasing macro-cell use via spectrum refarming, use of multiple-input and multiple-output (MIMO) antennas, etc.

NCO-driven VNC

The MNOs and the city create an NCO company to deploy and operate the 5G lamppost network as shown in Figure 3. Similar arrangements already exist for municipal fibre networks, e.g. Amsterdam owned 20% of the CityNet operator. The city covers the deployment costs of the lamppost structures and the sensors; the MNOs pay for the 5G antennas; together they share the costs of the civil works. The business ecosystem becomes complex given the number of

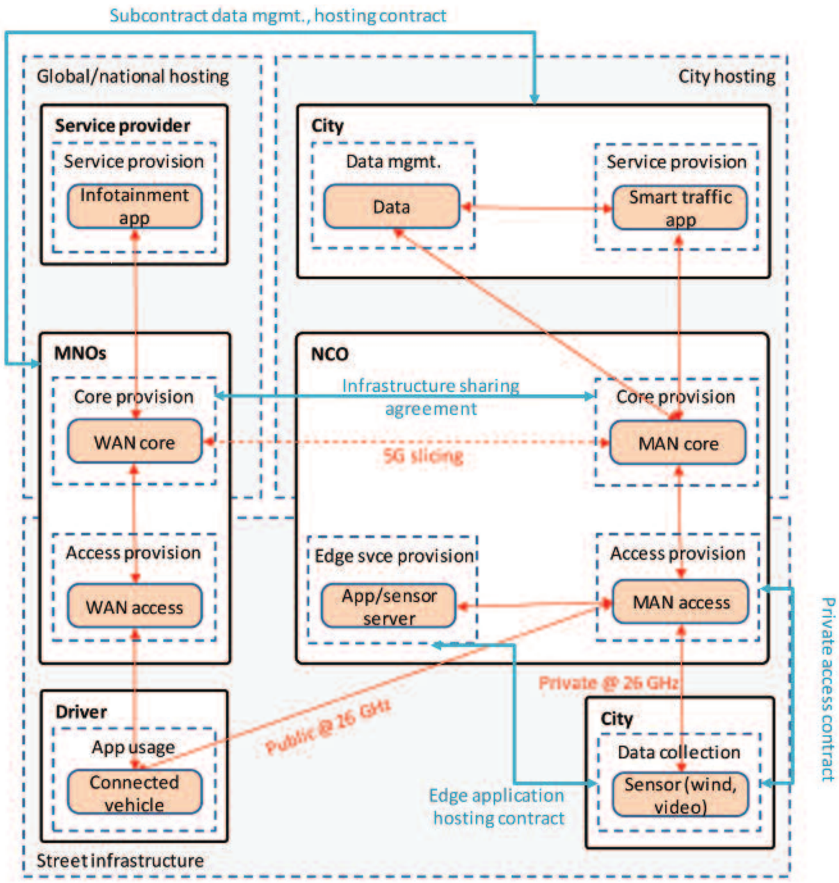


Figure 3: NCO-driven VNC

	Joint MNO-driven VNC	International cloud provider-driven VNC	NCO-driven VNC
Resources of VNC driver			
Small cell spectrum	MNOs' 26GHz nationwide	Unlicensed, e.g. 60GHz	MNOs' 26GHz nationwide City's 26GHz local
Fibre and power networks	BS backhaul	Data centre transit/peering	BS backhaul + city fibre
Technical competence	Advanced in 3GPP	Advanced in IEEE	Advanced in 3GPP
Broadband service			
MAN-WAN access	Roaming	Consumer switching	5G slicing
MAN competition	Monopoly	Monopoly	Service-based
Public/private network provider	Public	Public	Public and private
Application hosting			
City hosting location	MNOs' data centre	Cloud provider's data centre	The city uses MNOs' data centre
Edge hosting competition	MNOs' monopoly	Cloud provider's monopoly	MNOs' monopoly
Sensor data collection			
Sensor ownership and data mgmt.	MNOs	Cloud provider	The city owns / MNOs manage
Sensor data commercial availability	MNO control	Cloud provider control	City control

Table 3: Connectivity VNC comparison

Technical components	Business roles	Description
App server	Single-domain (SD) /Multi-domain (MD) service provision	The SD service provision role provides server-side SD applications (e.g. weather). The MD service provision role provides server-side MD applications (e.g. combining weather, transport, pedestrian flow).
App client	Service usage	Client-side applications are used via smartphones.
Sensor	Data collection	Sensors collect data.
Data base	SD / MD data storage	The SD data storage role stores SD data. The MD data storage role stores MD data via centralised (high performance) databases, and links decentralised (easy integration) databases.
File transfer program	Data buying/selling	Data is traded through retail human-conducted transactions.
e-commerce solution	Data trading	Data is traded through a one-stop-shop, i.e. the e-commerce solution, minimising the need for human intervention. A self-service data ordering system enables customised orders, selecting data from multiple sets.

Table 4: Business roles and technical components for urban data services

required contracts. The network operation is possibly subcontracted to a single MNO or a neutral actor (e.g. equipment vendor). The NCO equitably leases small-cell capacity via 5G network slicing for MNOs to exploit their own 26GHz spectrum. Prices for network slices may be regulated to ensure that non-MNO shareholders (i.e. the city, power companies) can recover investments and that MNO service-based competition works efficiently.

Optionally, the NCO can serve the city's internal usage by acting as a private network provider if a local spectrum license is obtained. For example, in Germany 100MHz of the 3.5GHz band have been reserved for local use. In Finland, 800 MHz of the 26 GHz band is reserved for local use. The city remains the owner of the sensor data but it subcontracts its management to the MNOs, given its limited computing resources and competences. Therefore, the existing telco cloud infrastructure becomes the default hosting site for city applications and data. The NCO deploys the edge hosting network under the strict supervision of MNOs to restrict interfaces to third-party edge cloud providers.

Results from urban connectivity analysis

MAN access provision, MAN core provision, and edge hosting are identified as new business roles. More importantly, a new actor is identified, i.e. the NCO, which allows non-MNO actors (i.e. the city, power companies, telecom tower companies) to become shareholders for the 5G lamppost network operation. The NCO-driven VNC offers improved feasibility, given 1) cost savings from MAN sharing and reuse of existing fibre networks, 2) 26GHz monopoly mitigation via service-based competition, 3) reuse of existing hosting resources via MNO data centre leasing or IT outsourcing, 4) city ownership of sensor data, and 5) possibility for the city to serve internal use as a private network provider as shown in Table 3.

Urban data analysis

Business roles and technical components

The technical components and business roles in the provision of urban data services are shown in Table 4.

Joint MNO-driven VNC

MNOs create a joint venture data company to increase revenues from service usage data from broadband and machine-to-machine subscriptions. MNO ventures for data sharing already exist to enable number portability and call routing, including NUMPAC in Finland. The venture reuses existing MNO hosting infrastructure to host new databases for MD data storage, including a centralised database for high-performance big data analytics but also linking remote data sources for easy initial data integration. The venture enables city stakeholders to increase data value and monetisation, facilitating cross-actor aggregation and trading, becoming a new sales channel (e.g. DAWEX data trading company). The e-commerce solution allows data buyers and stakeholders to acquire a combination of datasets via a self-service ordering system (i.e. one-stop-shop) with different pricing structures, including open data, barter, pay-per-download, flat-fee subscription. The venture enables data-competent stakeholders to improve their existing applications. A data transaction could include an insurance company acquiring a flat-rate subscription to have unlimited access.

International cloud provider-driven VNC

Cloud providers that typically provide services in addition to hosting (e.g. Google, Amazon), collect vast amounts of data from their applications (e.g. search, email, maps, e-commerce), from open APIs, and service providers' web pages. The cloud provider increases the value of individual datasets by aggregating them, increasing volume, and widening the scope, as shown in Figure 4. City stakeholders are not willing to share additional data with the cloud provider since this provider (e.g. Google) could create a competing service leaving them out of business. At the same time, the cloud provider is not willing to share the aggregated data with city stakeholders since it would risk an increase in service competition. Hence, the international cloud provider remains the

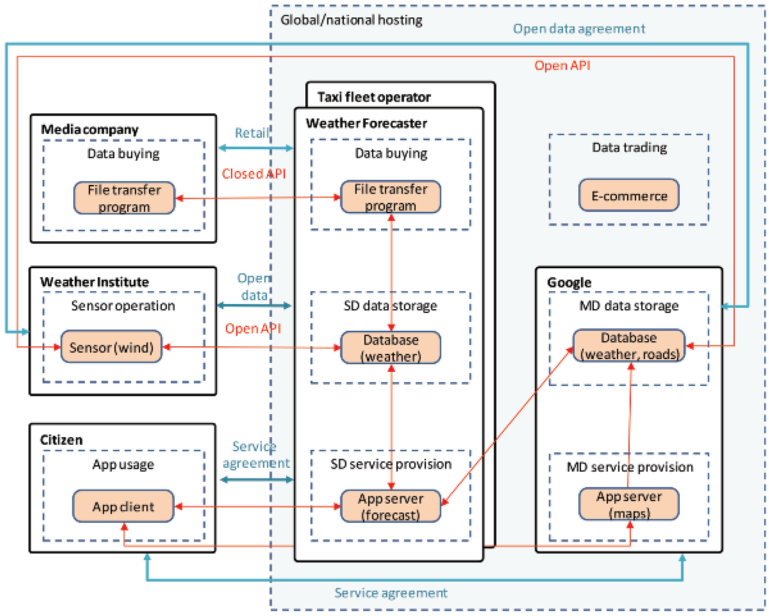


Figure 4: International cloud provider-driven VNC

leading provider of smart city applications combining multi-domain data, e.g. weather, road utilisation, business opening hours, and personal data.

NDO-driven VNC

The city controls vast amounts of municipal data (e.g. land ownership, building inspection archives), fragmented across hundreds of information systems. The city invests in its gradual integration creating a new database for MD data storage. The city establishes an NDO to offer support and consulting for the exploitation of these datasets, following the model of national statistics offices.

Examples of similar smaller initiatives include the Helsinki Infoshare portal and the Copenhagen data exchange [5]. As more data is aggregated from sensor networks (e.g. traffic light management, vehicle street flows), the city migrates data operations to MNOs' hosting infrastructure and implements business contracts like the Joint MNO data company. Nevertheless, the NDO can attract more/suspicious data holders, given the valuable complementary municipal data and the neutral city oversight. As a result, a larger number of data transactions are expected, facilitating the development of new data-based applications. Data service competition can be expected since other cities can generate substitute datasets. The VNC is shown in Figure 5.

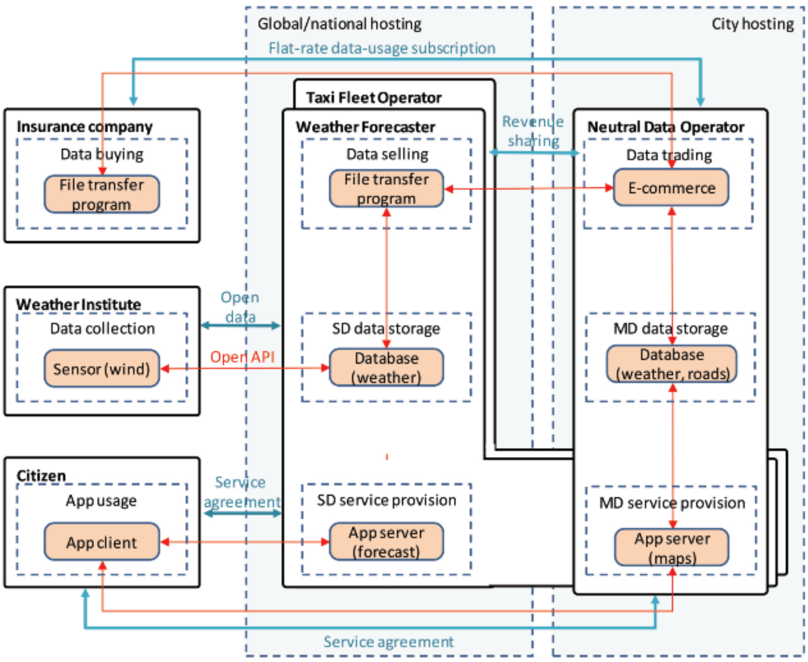


Figure 5: NDO-driven VNC

Results from urban data services

Data trading and MD data storage are identified as new business roles. More importantly, two new actors, i.e. the NDC and the MNO-driven joint venture data company, which can aggregate and trade data, are also identified. The NDO-driven VNC is the most feasible configuration, given the following synergies between the city and MNOs: 1) large city-data volumes match MNOs' hosting capacity and analytics competence, 2) valuable city data matches MNO commercial interest and distribution channels. In addition, 3) the neutral data aggregation point attracts suspicious data traders, 4) equitable stakeholder access to massive multi-domain data incentivises application development as indicated in Table 5.

Synergies across connectivity and data service provision

The following benefits and drawbacks can be expected from the merging of NCO and NDO actors, creating what some researchers refer to as the *big data virtual operator* [6], as shown in Figure 6:

- **Scale benefits from cloud computing and 5G virtualisation** - Computing resources can be optimised between Data trading, MD data storage, and Core provision since they are software-based and hosted in the same location, i.e. City Hosting. MAN Access can also partially benefit if baseband processing is centralised, as envisioned by 5G.
- **Tight data synchronization across hosting locations for mobile edge computing** - Real-time data from sensors, e.g. video streams, may need pre-processing on the edge, e.g. for event detection, before updating the city digital twin on the MD data storage (see example in Figure 6). Vice-versa, updates from

	Joint MNO-driven VNC	International cloud provider-driven VNC	NCO-driven VNC
Enabling resources of VNC driver			
Data hosting capacity	Medium	High	Medium
Categories of managed data service	Mobile service	Personal, App usage, etc.	Municipal + Mobile
Service dev. and data analytics competence	Medium	High	Medium
VNC data trading outcomes			
Ability to attract stakeholder data for trading	Medium	Low	High (neutral infrastructure)
Willingness to use managed data for trading	High	Low	High
Achieved volume of data trading	Medium	Low	High
VNC data-based application development			
Ability to attract stakeholder data for apps	Medium	Low	High (neutral infrastructure)
Willingness to use managed data for apps	High	High	High
Enabled data-based apps	Improvement of existing apps	More cloud provider apps	New stakeholder apps

Table 5: Data VNC comparison

centralised applications (e.g. in control rooms) may need prompt dissemination to the edge (e.g. low latencies). Hence, it would be desirable for technical components to share a common network domain, avoiding inter-stakeholder interfaces.

- **Single network domain for 5G URLLC** - URLLC requires fully integrated network control functions across city / edge resources to guarantee end-to-end service quality. While network slice management can be distributed among different stakeholders, an integrated actor will enable strict reliability and latency, for example, to provide remote driving services.
- **Business complexity** - Different MNO strategies for mobile edge computing / URLLC may complicate a merging of NCO-NDO actors. For example, innovative MNOs will want to exploit first-mover advantage whereas conservative MNOs may wish to delay launch until the service/demand is better understood.

AUTHORS' CONCLUSIONS

This article has offered a qualitative interview-supported VNA to identify alternative VNCs for urban provision of 1) small cell connectivity and street-level data collection and for 2) data commerce via multi-domain data aggregation and trading.

After a systematic comparison, it is concluded that VNCs that are driven by a city / MNO partnership via an NCO and an NDO provide improved feasibility for provision of both connectivity and data collection and data commerce. In general, such VNCs benefit from higher cost savings, enhanced market neutrality, higher incentives for local application development, and unique city / MNO complementarities. The business complexities associated with joint ventures and use of neutral infrastructure can be mitigated by the benefits identified.

In comparison, the NCO-driven VNC can benefit from higher cost savings, due to infrastructure sharing as well as reuse of existing fibre/spectrum/hosting resources, monopoly mitigation via 26GHz service-based competition and city oversight on sensor data collection/management, and optional city-internal private network service. The NDO-driven configuration can benefit from city / MNOs complementarities, including vast/valuable municipal-data together with MNOs' analytics competence and commercial/hosting resources. This configuration can aggregate larger data volumes, including municipal-data and attract suspicious data traders, given its neutrality. As a result, local application development may be incentivised via equitable stakeholder data access.

Some of these benefits can be achieved through a city / international cloud provider partnership that uses unlicensed spectrum (via IEEE-based wireless technology) or locally licensed spectrum (via 3GPP-based wireless technology). With unlicensed spectrum, mobile service quality may suffer from a suboptimal handover between small and macro cells. With licensed spectrum, MNOs could minimise use of new entrant infrastructure. Also, international cloud providers, who typically provide services in addition to hosting, may hinder equitable stakeholder data access, preventing the development of competing local services. VNCs are highly sensitive to the level of city involvement, for example, including investment via local companies, e.g. utilities.

Finally, the synergies for NCO-NDO integration were identified, facilitating the provision of 5G

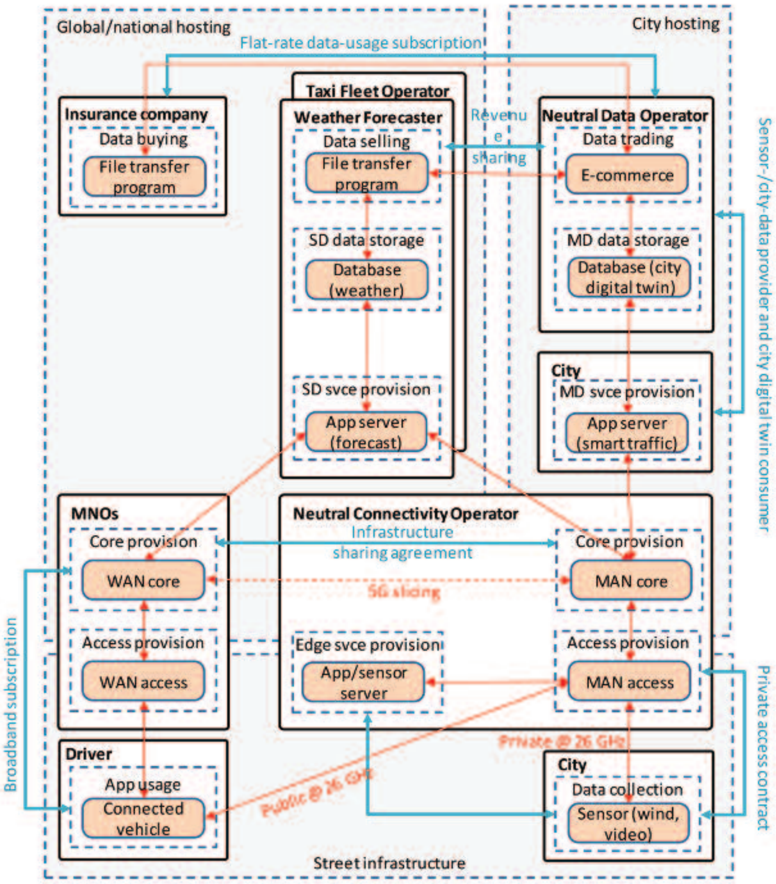


Figure 6: NDO and NCO integration

mobile edge computing with tight synchronization across hosting locations, enabling URLLC.

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ABBREVIATIONS

BS	Base station
MAN	Metropolitan Area Network
MD	Multi-Domain
MNO	Mobile Network Operator
NCO	Neutral Connectivity Operator
NDO	Neutral Data Operator
SD	Singe-Domain
WAN	Wide Area Network
VNA	Value Network Analysis
VNC	Value Network Configuration
URLLC	Ultra-Reliable Low Latency Communication