Savunen, Tapio; Hämmäinen, Heikki; Kilkki, Kalevi; Kekolahti, Pekka

The role of mobile network operators in next-generation public safety services

Published in:
Telecommunications Policy

DOI:
10.1016/j.telpol.2022.102489

Published: 01/04/2023

Document Version
Publisher's PDF, also known as Version of record

Telecommunications Policy 47 (2023) 102489

Contents lists available at ScienceDirect

Telecommunications Policy

journal homepage: www.elsevier.com/locate/telpol

The role of mobile network operators in next-generation public safety services

Tapio Savunen *, Heikki Hämmäinen, Kalevi Kilkki, Pekka Kekolahti

Aalto University, School of Electrical Engineering, Department of Information and Communications Engineering, Finland

ARTICLE INFO

Keywords:
Mobile network operator
Public safety
Business model
4G/5G
Mobile broadband

ABSTRACT

Field of research: This research is in the field of public safety communications in mobile broadband 4G/5G networks. The focus is on mobile network operators and their business opportunities in the public safety market.
Purpose: The purpose of this research is to provide a review of ongoing public safety mobile broadband projects in which mobile operators play a key role. In addition, a business model analysis is presented to determine the role of mobile operators in these projects. A comparison of the two key business models is also included to reveal their general characteristics.
Methods and data: The research used a qualitative method, an inductive case study. This method was used to draw general conclusions from a small number of case studies based on ongoing public safety mobile broadband projects. The Casadesus-Masanell and Ricart framework and the business model canvas were used to analyse and compare the two key business models discussed. Data were collected from a variety of sources, including company reports, press releases, international events and conferences, and selected interviews with managers in charge.
Findings: The results show that mobile operators have new business opportunities in the public safety market. Their existing mobile networks can be used for public safety services with certain enhancements. Within existing projects, mobile operators have different business models. The two analysed models were found to require different resources and offer different business opportunities for mobile operators. Procurement authorities responsible for selecting business models are encouraged to pay attention to the choice of model based on, for example, strategic objectives.
Value: Very little research has been done on the business opportunities of mobile operators in the public safety market. In this area, this study lays the groundwork for new research. Procurement authorities can use the results when deciding on the business model. Mobile operators can benefit from these results by better understanding their own roles in public safety projects and when assessing the business opportunities of a particular project.

1. Introduction

Reliable and secure wireless communications are a prerequisite for public safety operations, such as police, fire and rescue, and paramedic services. Until recently, wireless communications for public safety have been based on narrowband radio technologies such

* Corresponding author.
E-mail address: tapio.savunen@aalto.fi (T. Savunen).

https://doi.org/10.1016/j.telpol.2022.102489
Received 20 September 2022; Received in revised form 29 December 2022; Accepted 30 December 2022
Available online 5 January 2023

as *Terrestrial Trunked Radio* (TETRA), *Tetrapol*, and *Project 25* (P25) (Fantacci et al., 2016). Due to the limitations of narrowband technologies and technological advances in wireless technology, public safety agencies are moving to broadband communications based on standardised 4G/5G mobile technologies (Yarali, 2020).

Broadband communications enable new services in public safety field operations, which improve the efficiency of field operations and the safety and security of first responders and citizens. Such services include, for example, video stream from field to command centre to improve situational awareness, and access to operational data in the field, such as maps and construction drawings (Peltola & Hämmäinen, 2018). The socioeconomic value of public safety services made possible by mobile broadband communications in Finland is estimated to be 40–94 euros per inhabitant per year (Peltola & Hämmäinen, 2018). Similarly, in Great Britain, increased productivity of police operations due to mobile broadband services could provide 5–20% savings (Grous, 2013). According to a study published by the European Commission, an annual savings of 5% when public safety services work more effectively in emergencies would amount to 24 billion euro in the EU (Forge et al., 2014).

This development opens up new business opportunities for mobile network operators (MNOs), as the technologies that will be used for public safety are the same 4G/5G technologies that MNOs already use. Therefore, MNOs can serve public safety agencies by leveraging their existing mobile networks with certain enhancements (Peltola & Hämmäinen, 2018). The use of networks operated by MNOs for public safety is also an opportunity for governments and regulators, as governments do not need to invest in dedicated nationwide public safety networks, and regulators have no need to allocate radio spectrum (Productivity Commission, 2015; Norwegian Directorate for Civil Protection, 2018).

Public safety field operations set extraordinary requirements for wireless communications. Often, human lives can be at stake. Therefore, the availability and security of services must be at a high level (Yarali, 2020). These are called *mission-critical* (MC) requirements. Mobile networks designed for consumers and enterprises do not meet the needs of public safety. Coverage usually needs to be extended to ensure high service availability, and the security and resilience of networks must be hardened, including power supply and transmission hardening (Peltola & Hämmäinen, 2018). In addition, the quality of the service mechanisms of 4G/5G technologies need to be used to differentiate the services of public safety users and MNOs' regular customers when served by the same network (Hallahan & Peha, 2013).

In recent years, an increasing number of research papers on public safety services and 4G/5G technologies have been published, primarily focusing on technological questions. Some of these also apply to MNOs. However, they do not deal with MNOs' business, but with topics such as how to manage the quality of service of the MNO's radio network when it is shared between public safety and other users with different needs (Höyhtyä et al., 2018; Hallahan & Peha, 2013). In addition, the socioeconomic value of the various implementation options for public safety networks, with one option being MNOs, has been analysed (Peltola & Hämmäinen, 2018). Practitioners have also published documents related to MNOs and public safety, such as a document published by the TCCA (2018) on new business opportunities for MNOs in critical communications markets, and the Norwegian Directorate for Civil Protection (2018) published a document on different models for organising MC services with MNOs in Norway. An industry example is Ericsson's survey of 100 MNOs on their plans for 5G adoption; 41% of MNOs considered public safety as a potential new business opportunity (Laxdal, 2016). In summary, there are almost no studies that deal with MNO business in the public safety market. Clearly, more research is required.

Today, there are known to be five national public safety mobile broadband projects in which MNOs participate that are at least in implementation phase. These projects are Virve 2.0[1] in Finland, Réseau Radio du Futur (RRF) in France, Safe-Net in the Republic of Korea, Emergency Services Network (ESN) in the United Kingdom, and First Responder Network (FirstNet) in the United States (Erillisverkot, 2021c; Carmona, 2021; Yarali, 2020; Home Office, 2021a; FirstNet Authority, 2021[2]). These projects are based on public tenders organised by public procurement authorities (Hankintailmoitukset, 2019; Hoffman, 2015; TED, 2019b; TED, 2020). Public tenders are usually regulated, for example, in the EU, by the laws of the member states that implement EU directives. Organisations that meet the qualification requirements can participate in a public tender. The criteria used to rank offers vary, but usually price is an important factor, assuming that offers fulfil the tender's requirements.

This paper provides a comprehensive review of the five ongoing nationwide public safety mobile broadband projects with MNO involvement and studies the business models of these projects and their characteristics from the MNO's point of view. The procurement authorities decide on the business models, and they are thus given to MNOs.

The research questions are as follows.

- What are the characteristics of ongoing nationwide public safety mobile broadband projects with MNO involvement?
- What are the projects' business models and their key characteristics?
- What are the MNOs' business opportunities and key assets needed in different business models?

The structure of the paper is as follows: Section 2 describes the research methods and data sources. The results of the paper are divided into two sections. Section 3 reviews ongoing public safety mobile broadband projects. The key features of the projects are summarised in tabular form. Brief descriptions of each project area also provided, including the background, network configuration, business model, and status of each project. Section 4 provides an in-depth MNO business model analysis and a comparison of two

[1] There are two different names in public use: Virve 2 and Virve 2.0. This paper uses Virve 2.0.

[2] The document contains FirstNet references that refer to the federal authority, listed as FirstNet Authority, and to the web portal maintained by AT&T, listed simply as FirstNet.

selected projects with different business models. Section 5 is the discussion of these findings, and Section 6 contains the conclusion.

The results of the paper can be used by MNOs considering entry into the public safety services. Additionally, procurement authorities can use these results when planning public procurement for public safety services. This study also lays the groundwork for new research dealing with the MNOs' business in the public safety market.

2. Research Methods

2.1. Inductive case study method

Currently, there are five nationwide public safety mobile broadband projects in which MNOs play a key role, and only two have reached the production phase and serve public safety users, as discussed in Section 3. Therefore, the availability of data sources is relatively limited. This motivated the use of a qualitative research method.

The qualitative method that was chosen for this research is an inductive case study method that aims to build generalised conclusions from data collected from a small number of case studies. It is an appropriate method in new research areas and in the early stages of research that lacks an existing theoretical framework. The method is a well-formulated process with consecutive steps, including selecting cases, collecting data, analysing data, shaping hypotheses, and reaching closure. A key element of the method is continuous iteration and comparison of theory and data until a solid theory that fits the data is achieved (Eisenhardt, 1989).

The ongoing public safety mobile broadband projects formed the cases that served as the basis for drawing general conclusions in this research. Since projects are case study cases, the term *case* would be justified when referring to a project. On the other hand, when discussing about projects in the project review, the term *project* would be justified. To avoid the difficult and perhaps confusing use of these two terms interchangeably, the term project is used in both roles – to refer to projects involving MNOs and to case study cases.

Fig. 1 illustrates the relationship between the steps of the inductive case study method and the structure of the paper. The structure is not directly based on the steps of the method, but several steps have counterparts in the content of the paper.

2.2. Business model analysis

The business model analysis and the selection of methods was guided by the research questions. The goal was to analyse MNO business models in nationwide public safety mobile broadband projects to understand MNOs' strategic options and business

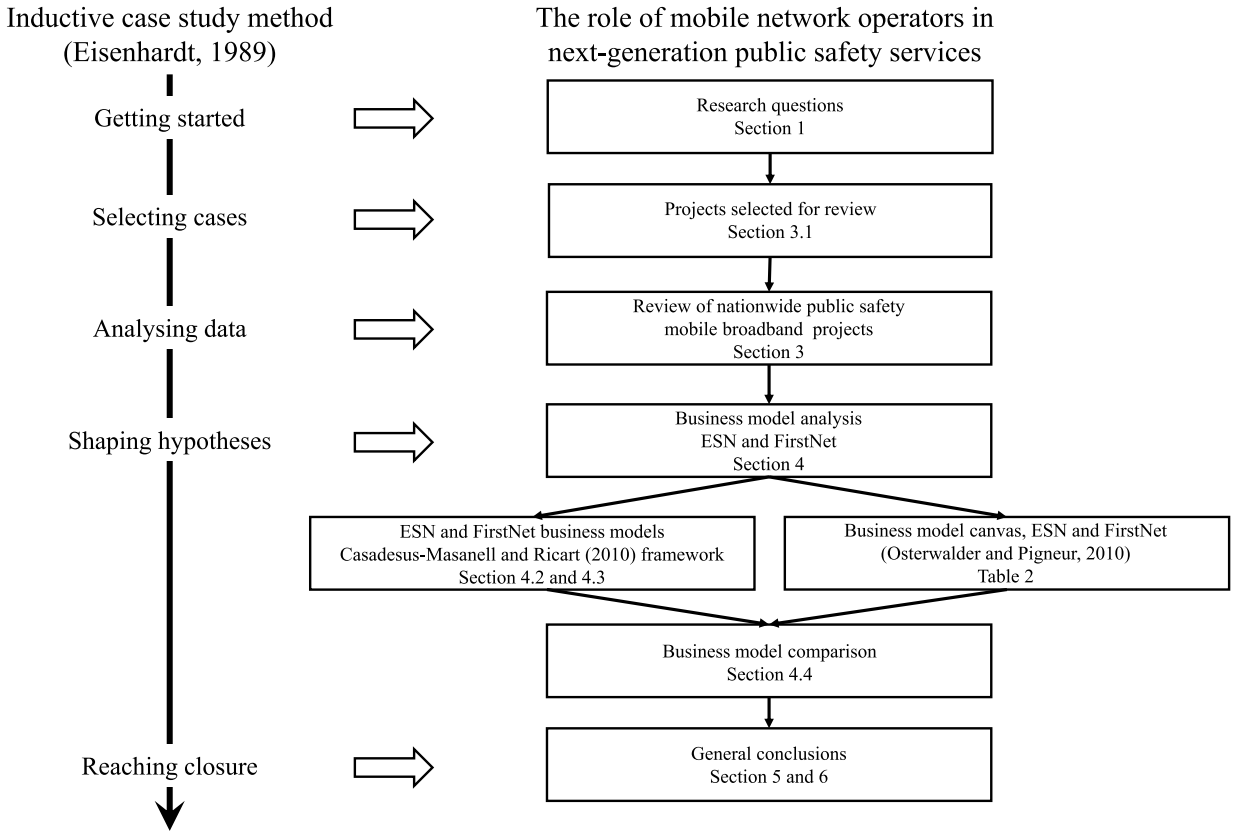

Fig. 1. The relationship between the steps of the inductive case study method and the structure of this paper.

opportunities in the public safety services market. In addition, the analysis included the role and responsibilities of the MNO in the project, and the key assets and investments required.

Two projects were selected for in-depth analysis, which consisted of two phases. In the first phase, the business model of the project and the role of the MNO were analysed separately for both selected projects, see Sections 4.2 and 4.3. The second phase compared the business models of the MNOs in these projects, see Section 4.4.

In the first phase, the Casadesus-Masanell and Ricart (2010) framework was used to analyse individual projects. This framework was chosen because 1) it provides a strategy-oriented view, 2) it can be used to describe interdependencies with other actors, such as cooperating companies, 3) it is capable of analysing the dynamic nature of the relationships between management choices and business consequences, and 4) it can be used to analyse *virtuous cycles* that reinforce consequences over time (Sánchez & Ricart, 2010).

The Casadesus-Masanell and Ricart framework provides a strategy-oriented view, which is needed to analyse MNOs' strategic options. The other two general views of business model frameworks are technology- and organisational-oriented modelling (Wirtz et al., 2016).

The Casadesus-Masanell and Ricart framework has two key components: choices and consequences. An organisation's management makes choices. Choices can be about the organisation's policies and assets and the governance of the organisation. Consequences are the implications of management's choices. Consequences can be either flexible or rigid. Flexible consequences react quickly when the preceding choice changes, while rigid choices react slowly; for example, a company's culture is usually slow to change, even when there are active attempts to change it (Casadesus-Masanell & Ricart, 2010). The management choices and business consequences can form virtuous cycles that reinforce consequences over time. For example, a growing customer base will increase profits that, in turn, will allow new investments to be made, resulting in further growth of the customer base. Several choices can complement one another and reinforce their impact on the consequences (Sánchez & Ricart, 2010).

The Casadesus-Masanell and Ricart framework has its strategy orientation in business-model innovations driven by globalisation, deregulation and the development of information and communications technology (Wirtz et al., 2016). However, this research does not follow the tradition of business model innovation, although the Casadesus-Masanell and Ricart framework was chosen. A typical assumption in business model innovation research is an organisation's ability to develop and change its business model (Geissdoerfer et al., 2017; Euchner & Ganguly, 2014). This is not the situation for the projects of this research. For MNOs the business model is given in the public tender. The MNO's first choice is whether to participate in the tender. If it participates, it must study the given business model and consider its implications.

For the second phase – comparison of MNO business models in the selected projects – in addition to the results of the Casadesus-Masanell and Ricart framework analysis, the *business model canvas* introduced by Osterwalder and Pigneur (2010) was used. The business model canvas is a template comprised of nine different strategic business aspects, such as customer segments, value proposition, and channels. According to Wirtz et al. (2016), the business model canvas covers seven of nine business model components analysed in the research, and only three of the 16 business model concepts have received such a high ranking. Therefore, the business model canvas is suitable for comparing business models because it covers most of the business model components. In addition, many of its components provide valuable information for the research questions.

A typical way to use the business model canvas is to follow the template provided by Osterwalder and Pigneur (2010). It consists of nine rectangles in a specific order. Each rectangle represents components of the business model with given names and interpretations. This research follows the components of the business model canvas with their given names and interpretations. However, the layout is not the template model but a simple tabular format.

The position of the two business model analysis methods in this research is illustrated in Fig. 1.

2.3. Data collection

The data on nationwide public safety mobile broadband projects were collected from a variety of sources. These include company reports and press releases, international events and conferences, magazines, and the *Official Journal of the European Union* (public procurements). In addition, the managers of the organisations responsible for the public safety communications projects were interviewed. The data sources are documented as references in the project review in Section 3. The business model analysis in Section 4 is based on the data presented in Section 3.

3. Review of nationwide public safety mobile broadband projects

3.1. Projects selected for review

The criteria for selecting the public safety mobile broadband projects for review were that they 1) are nationwide, 2) have reached the implementation phase or already be in operation and serving public safety users, and 3) involve one or more MNOs. Today there are known to be five such projects: Virve 2.0, RRF, Safe-Net, ESN, and FirstNet. These are well-known projects, and the critical communications community is following the progress of these projects, for example, in the plenary meetings of TCCA's Critical Communications Broadband Group.[3]

[3] See minutes of TCCA/CCBG plenary meetings #22 21–22 Oct 2020, #23 29–30 Apr 2021, #24 21–22 Oct 2021; #25 21–22 April 2022; #26 3–4 November 2022; https://tcca.info/broadband/critical-communications-broadband-group/.

There are also other initiatives and projects that do not fulfil all the listed selection criteria and they were excluded from this research. For example, several countries have not yet reached the implementation phase but are preparing a national public safety mobile broadband project using an MNO, such as in Sweden (MSB, 2021), Norway (Norwegian Directorate for Civil Protection, 2018), and Australia (Critical Comms, 2021). There are also regional networks without nationwide coverage. For example, Faroese Telecom provides MC mobile broadband services to Faroese public safety agencies (Ericsson, 2020). Finally, there are dedicated mobile broadband networks for public safety in which MNOs have no role, such as in the United Arab Emirates (Chinta et al., 2019).

Information about the five public safety projects reviewed is summarised in Table 1. All information in the table is based on Sections 3.3 to 3.7, except for the number of mobile users in the countries. These are based on the International Telecommunication Union (ITU, 2022) statistics.

3.2. Key concepts

In this section, the terminology used in the project review to classify business models and offering elements is defined. The aim is to employ widely used terminology.

In this research, the business model is fully defined in two dimensions with a two-value attribute. By combining these two dimensions, we get four different models. The first dimension divides the projects based on the number of actors involved in the provision of public safety services. In the *single-actor model*, one actor is responsible for all elements required for complete public safety services, including network services, devices, applications and customer services. The other option is called *multi-actor model*, where several actors are responsible for complete public safety services.

The second dimension divides projects according to the primary radio access network (RAN) used by public safety users. If the network is used only by public safety users, it is called a *dedicated network*. Alternatively, in a *shared network*, the MNO's RAN is used by public safety users and the MNO's regular customers – that is, consumers and enterprises.

Fig. 2 illustrates the positions of the reviewed projects on the map of four business models. Safe-Net follows the *multi-actor dedicated-network* model, where MNOs are responsible for the deployment and maintenance of the dedicated network, see Section 3.5. The business model of FirstNet is the *single-actor shared-network* model. As an MNO, AT&T is responsible for all end-to-end public safety services, including devices and applications (see Section 3.7). All of the European projects reviewed use a *multi-actor shared-network* model. There are several actors in charge of provisioning of public safety services and the network is shared between public safety users and MNO's regular customers (see Sections 3.3, 3.4 and 3.6). The MNO's role is to provide shared MC RAN services (3rdGeneration Partnership Project [3GPP], 2020). In addition, the MNO can also offer some core network services.

An interesting observation is that the typical model in narrowband public safety networks today is the *single-actor dedicated-network* model, which is not present in the reviewed projects. For example, in both Finland and the United Kingdom, there is a dedicated TETRA narrowband network with the single-actor model, called Virve (Erillisverkot, 2021a) and Airwave (Airwave, 2022). Now, in both countries, the trend is in the opposite direction, a shared MNO's network with the multi-actor model.

Public safety users need several elements for complete communications services. These include network services, applications, devices and accessories, and customer services. Network services that meet the needs of public safety users are called *MC RAN services*. When the MNO's existing network is used and shared with public safety users, the provision of MC RAN services requires the MNO to extend the coverage of the network and harden network resilience and security (Peltola & Hämmäinen, 2018). In addition, the *quality of service, prioritisation, and pre-emption* (QPP) functionalities of 4G/5G technologies are required to enable adequate service quality for public safety users in a shared network (Hallahan & Peha, 2013).

MC applications are defined and standardised by 3GPP for public safety and other critical purposes. MC applications include push-to-talk (*MCPTT*), *MCVideo*, and *MCData*. Together, these are called *MC services (MCS)* (Lair & Mayer, 2017). They are also widely known as MCX services. The term MCS is used in this paper.

A variety of other applications have also been designed for public safety users. They are not standardised but have been developed for a specific purpose. They are called public safety applications.

Customer services are needed at different stages of the lifecycle of public safety communications services. Examples include deployment services, training, device lifecycle management services, 24/7 support centres, and security operations centre services. End-to-end service verification is also needed throughout the service lifecycle to ensure the proper integration of different service elements.

Fig. 3 illustrates the division of responsibilities for the reviewed projects with the shared-network model. The multi-actor model is used in all European projects, and the single-actor model in the FirstNet project.

3.3. Finland – virve 2.0

3.3.1. Background

In Finland, there is a nationwide TETRA network for all Finnish public safety agencies called Virve. Critical infrastructure organisations and rail traffic operators also use Virve services. The network is owned and operated by the government organisation Erillisverkot (2021a), it has about 51 thousand users, and it provides voice and short message services.

The Virve network offers coverage for about 96% of Finland's geographical area (Melkko, 2021). Most Virve users have expressed being satisfied or very satisfied with Virve services. However, the data bit rate is limited due to TETRA technology, and the Virve network does not support the modern data applications required by users (Erillisverkot, 2021c). In 2019, the Finnish government decided on a new public safety network (Melkko, 2021), and Erillisverkot (2021c) initiated Virve 2.0 to deploy public safety mobile

broadband services based on 3GPP standards and 4G technology.

3.3.2. Network configuration

Virve 2.0 is based on the multi-actor shared-network model. The MNO does not provide core network services, which is called the *multi-operator core network* (MOCN) configuration (3GPP, 2020). There is a primary MNO that shares its radio network between the MNO's regular customers and Virve 2.0 users. Public safety services are prioritised using QPP functionalities. Virve 2.0 users have a dedicated LTE core network. No radio spectrum is reserved for public safety in Finland, but MNO frequency bands are used (Melkko, 2021).

3.3.3. Business model

Government-owned Erillisverkot is the service operator of Virve 2.0. Erillisverkot is responsible for the Virve 2.0 project, as well as end-to-end services for users (Erillisverkot, 2021c). Elisa, one of Finland's three largest mobile operators, was selected as the primary MNO offering MC RAN services (Elisa, 2020). National roaming is an implementation option for using the services of other mobile operators (Erillisverkot, 2021c).

As the primary MNO, Elisa is required to extend the coverage, capacity, and resilience of the network to fulfil the requirements of Virve 2.0 and public safety users. The coverage target is to obtain comparable coverage with the existing Virve network – that is, about 96% of Finland's geographical area. Erillisverkot and Elisa have a 10-year contract period (Elisa, 2020; Melkko, 2021), after which Virve 2.0 radio access services can be re-tendered.

According to Finnish legislation, Erillisverkot has the exclusive right to provide MC mobile communications services to public safety agencies. Therefore, Erillisverkot and Elisa do not face competition in public safety communications (Melkko, 2021). The ultimate goal is to migrate all Virve users to Virve 2.0. When existing Virve services are no longer needed, the network can be closed (Erillisverkot, 2021c).

3.3.4. Status

The Virve 2.0 project is in the implementation phase. The MNO and the core network supplier have been selected. The goal is to introduce Virve 2.0 services, which will replace the current Virve service, in early 2023. The parallel use of Virve and the new Virve 2.0 services will continue until at least 2025 (Erillisverkot, 2021c). One of the design goals of the project has been that group communications services must operate between Virve and Virve 2.0 during the migration period.[4] The estimated number of Virve 2.0 users is 50 thousand (Erillisverkot, 2021c).

3.4. France – Réseau Radio du futur

3.4.1. Background

In France, there are two nationwide Tetrapol networks: INPT for police and rescue forces and RUBIS for the Gendarmerie, the French rural police. Together, these networks serve 220 thousand users. The networks are owned and operated by the French government (Tetrapol, 2022).

The limitations of narrowband technology have driven the initiation of a public safety mobile broadband project. Public safety users would like to have video and other new data applications in the field operations. The lifespan of narrowband technologies is also limited; therefore, migration to broadband solutions is also a risk-management measure (Carmona, 2021; Fenwick, 2019).

The French Ministry of the Interior launched public procurement in December 2020 for a programme called Réseau Radio du Futur [Radio Network of the Future]. The programme aims to bring mobile broadband services to all public safety users in France, with a total of 300 thousand users (Carmona, 2021; TED, 2020).

3.4.2. Network configuration

RRF is based on the multi-actor shared-network model, with two MNOs designed to provide MC RAN services and lower-core network services. This combination, RAN and lower-core network services, follows the convention of mobile virtual network operator (MVNO) businesses and is often called a *full-MVNO model* (Copeland & Crespi, 2011).

The plan is to provide public safety users with prioritised services using QPP functionalities. RRF services follow 3GPP's MCS standards to ensure compatibility with other service providers, such as those in neighbouring countries (Carmona, 2021).

The coverage of RRF is based on the coverage of the MNOs' networks. The plan also includes deployable networks and additional fixed radio sites to extend coverage and capacity on an as-needed basis. The MNOs use their own radio spectrum. In France, there are two dedicated bands for public safety, B28 and B68, in the 700 MHz band for RRF coverage extensions. National roaming can also be used to back up the coverage and capacity of selected MNOs (Carmona, 2021).

3.4.3. Business model

RRF procurement is divided into three lots. The first lot is for MC RAN services with two MNOs, including lower-core network services. The selected MNOs are Orange and Bouygues Telecom (Donkin, 2022). The elements belonging in the second lot include the

[4] Email interview with a senior manager of Erillisverkot, May 2022.

upper LTE core network, an MCS solution, a Tetrapol gateway, devices, SIM cards, and security solutions, among other things. The end-to-end integration services for the elements of the three lots are also in the second lot. The third lot includes management solutions, business support systems, and enterprise mobility management (TED, 2020).

The French government has decided to establish *The First Responders Operational Mobile Communications Agency* called *ACMOSS*. The agency is planned to be responsible for building and operating RRF, including a 24/7 network operations centre, and defining future strategies, together with stakeholders (Mellies, 2022).

3.4.4. Status

The completion of the RRF procurement was announced in October 2022, and the project has entered the implementation phase (Donkin, 2022). The goal of the French Ministry of the Interior is to make RRF available for the French Summer Olympics in 2024 and to migrate public safety users from the INPT and RUBIS networks to RRF by 2025 (Carmona, 2021).

3.5. Republic of Korea – Safe-Net

3.5.1. Background

In 2014, the Republic of Korea decided to build a dedicated mobile broadband network for public safety (Waring, 2018). The decision included the allocation of a radio spectrum for public safety. The driver behind the decision was the existence of numerous public safety networks based on different technologies, such as analogue, TETRA, and iDEN, which did not provide interoperability between public safety agencies. The aim was to replace these networks and ensure interoperability (Yarali, 2020).

3.5.2. Network configuration

Korean Safe-Net is a combination of three LTE networks: PS-LTE for public safety, LTE-R for railways, and LTE-M for maritime users (Hwang & Kim, 2020). They share the same frequency band (B28 in the 700 MHz band, 2 × 10 MHz).

PS-LTE is planned to be used by 333 agencies belonging to eight user categories – fire, electricity, coast guard, military, police, paramedic services, gas, and government (Hong & Kim, 2019). The estimated number of user devices is 240 thousand for PS-LTE, 10 thousand for LTE-R, and 35 thousand for LTE-M (Kim, 2021).

Safe-Net technology was verified in two pilot projects in 2015–2018. The second pilot phase provided support for the 2018 PyeongChang Winter Olympic and Paralympic Games. The deployment of PS-LTE took place in three phases in 2018–2021 (Hong, 2020; Hong & Kim, 2019).

For network operations, there are three geo-redundant operation centres in different regions of the country: Seoul, Daegu, and Jeju. Operation centres provide LTE core services, MCPTT services, and network management (Hong, 2020; Hwang & Kim, 2020).

The coverage of the PS-LTE network was built using dedicated networks of LTE radio sites (17 K + base stations). The coverage and capacity of other networks can also be used through network sharing, including commercial mobile networks and the LTE-R and LTE-M networks. The fourth element is deployable networks, either based on vehicles or portable solutions, such as backpack cells. LTE-M provides coverage up to 100 km from the coast, and LTE-R provides coverage for more than 4800 rail kilometres (Hong & Kim, 2019).

3.5.3. Business model

Safe-Net follows the multi-actor dedicated-network business model. Construction of the PS-LTE network was awarded to Korea Telecom (KT) and SK Telecom (SKT). KT is in charge of two districts, and SKT is in charge of one. KT was also responsible for building operation centres (Hong, 2020). Government ministries oversee network operations and MCPTT services.[5]

The administration of Safe-Net is shared between several ministries: the Ministry of the Interior and Safety oversees PS-LTE, the Ministry of Oceans and Fisheries oversees LTE-M, and the Ministry of Land, Infrastructure, and Transportation oversees LTE-R. Safe-Net Forum coordinates the research, standardisation, and government policies in Safe-Net (Hong & Kim, 2019).

3.5.4. Status

PS-LTE services were introduced in 2020, and nationwide coverage was reached in 2021 (Cho, 2021; Hong, 2020). The migration of all public safety users is planned to take place between 2020 and 2027. Areas for future development include device-to-device and air-to-ground communications, IoT sensors in public safety, and the gradual introduction of 5G (Hong & Kim, 2019).

3.6. The United Kingdom – Emergency Services Network

3.6.1. Background

Since 2000, the United Kingdom has had a TETRA network for public safety users called Airwave, which offers voice and short message services. The network has approximately 300 thousand users from more than 300 public safety agencies and covers 99% of the United Kingdom's land mass. The network is owned and operated by a private company (Airwave, 2022).

The performance of Airwave services is considered to be very good, although Airwave's data transfer speed is limited, and

[5] Email interview with a senior manager of Safe-Net Forum, February 2022

broadband services are not available. Additionally, the Home Office[6] considered the price of Airwave services too high (IWCE's Urgent Communications, 2013).

Due to the drivers of potential cost savings and broadband data services, the Home Office started a project in 2011 to launch the ESN to replace the TETRA-based Airwave network with 4G/LTE services (National Audit Office, 2019). The estimated user base is 300 thousand public safety users, 45 thousand vehicles, and 66 aircrafts in England, Scotland, and Wales (Home Office, 2021a).

3.6.2. Network configuration

The ESN is based on a commercial MNO's LTE network with extended coverage. The MNO is EE, part of the British Telecom Group. QPP functionalities are used to prioritise public safety services. For public safety users, there is a dedicated radio spectrum only for air-to-ground communications at 5 MHz in LTE band 40; otherwise, the EE spectrum is used (TED, 2019b). Another actor, a solution supplier, provides public safety solutions, including an MCPTT application (TED, 2019a).

The ESN has several elements to extend radio coverage to meet the needs of public safety users. The basis of the coverage is EE's existing LTE network, which EE is required to extend with about 700 new radio sites. The Home Office also has a plan to build 292 additional sites to improve coverage in the most rural and remote areas, called the extended area service. These sites will also be open to other operators (Home Office, 2021a; Jackson, 2021). Other activities for building coverage include Transportation for London's London Underground coverage and air-to-ground communications from 500 ft to 10,000 ft (BAI, 2021; RadioResourceMedia Group, 2022). The ESN is also likely to benefit from the proposed Shared Rural Network, a joint project by the United Kingdom government and the MNOs to expand rural coverage (EE, 2021a). For vehicles, EE provides coverage extenders to expand the coverage (EE, 2021b). The coastal coverage of the ESN is up to 7 nautical miles.[7]

3.6.3. Business model

The ESN business model is the multi-actor shared-network model. EE handles MC RAN services and the extension of coverage with new radio sites. EE is also in charge of providing radio equipment for extended area service radio sites and the installation and maintenance of the equipment. EE also provides a core network dedicated to public safety services and handles support services, such as availability and capacity management and the testing of mobile devices (TED, 2019b; EE, 2021a).

EE was originally awarded the ESN contract in December 2015, which was to run until 2021. Due to project delays, the contract was extended in 2019 and is currently set to expire in December 2024. The value of the contract is 895.7 million GBP. EE is paid for the delivery of network extensions on a milestone basis (TED, 2019b).

Another key actor is the supplier of public safety solutions. These solutions include an MCPTT application, user and device management, SIM card management, and customer support and service management (TED, 2019a).

Other areas that require their own suppliers include user devices and coverage solutions for aircrafts and the London Underground. About 100 control rooms also need to be upgraded to work with ESN (Clark, 2021; National Audit Office, 2019).

The Home Office plays a key role in the overall management of a relatively complex project with several contractors and various sub-projects. It is not clear who oversees end-to-end service integration, as stated in the report of the National Audit Office (2019).

3.6.4. Status

The ESN is in the implementation phase. The original goal was to replace the Airwave network with the ESN by the end of 2019. However, this turned out to be too ambitious, and in 2018, the Home Office announced a 'reset' of the project. The original plan could not be implemented for several reasons; for example, the solutions of suppliers were based on different versions of the standards, there was disagreement over responsibility for system integration and technical design, and there was late delivery of the 'related projects' (National Audit Office, 2019). As part of the project's reset, the Home Office decided to change the deployment model. Instead of targeting a 'big bang', an incremental model was chosen by taking into account the priorities of user agencies.

In 2021, the ESN programme shared a new schedule due to new delays; the goal is to begin migration in 2024 and shut down Airwave services by the end of 2026 (Jackson, 2021).

EE has extended its mobile coverage in rural areas with more than 600 new radio sites. About 19 thousand EE radio sites have also been upgraded, including the 800 MHz band for rural and indoor areas (EE, 2021a).

3.7. The United States – FirstNet

3.7.1. Background

The public safety communications market in the United States is highly fragmented. It is estimated that there are as many as 60 thousand public safety agencies, more than 10 thousand *land mobile radio* (LMR) networks, and about three million public safety users, including police, fire, and paramedics (Atkinson, 2020). The main LMR technologies used in the United States are P25, analogue, and *Digital Mobile Radio* (DMR) (Darrand, 2020).

The attacks of September 11, 2001 in the United States triggered the next-generation nationwide network for public safety. The 2004 9/11 Commission report identified problems in public safety communications. First responders were unable to communicate

[6] 'The Home Office is the lead government department [of the United Kingdom] for immigration and passports, drugs policy, crime, fire, counter-terrorism and police (Home Office, 2021b).'

[7] Email interview with a senior manager of the Home Office, April 2022.

Table 1
Nationwide public safety mobile broadband projects.

Name	Virve 2.0	Réseau Radio du Futur	Safe-Net	Emergency Services Network	FirstNet
Country	Finland	France	Republic of Korea	UK	US
Key drivers	No broadband services	No broadband services	Numerous networks, no interoperability between agencies	High cost of services, no broadband services	No interoperability between agencies
Status	Implementation	Implementation	In operation	Implementation	In operation
Number of potential users	50 thousand	300 thousand	PS-LTE: 240 thousand LTE-R: 10 thousand LTE-M: 35 thousand	300 thousand	3 million public safety users, also extended community users; 4 million connections in December 2022
Mobile users in the country 2021, million (ITU, 2022)	7.2	72.8 (year 2020)	72.6	79.8	361.6
Share of public safety users	0.7%	0.4%	0.4%	0.4%	0.8%
Business model	Multi-actor shared network	Multi-actor shared network	Multi-actor dedicated network	Multi-actor shared network	Single-actor shared network
Project configuration	One MNO Service operator	Procurement lots: 1) Two MNOs 2) Upper LTE core, MCS, devices, end-to-end integration 3) BSS/EMM solutions	Two MNOs Ministries	One MNO Supplier of public safety solutions Several related projects	One MNO
Spectrum	No dedicated spectrum	B28 2 × 3 MHz B68 2 × 5 MHz	B28 2 × 10 MHz	Air-to-ground: B40 5 MHz	B14 2 × 10 MHz
Coverage solution	MNO network with extended coverage National roaming is an implementation option	Coverage of two MNOs 700 MHz coverage extensions Deployable solutions National roaming	Dedicated radio sites Sharing of other networks Deployable solutions	MNO network with extended coverage Extended service area Air-to-ground London Underground Coverage extenders	MNO network with extended coverage and B14 Deployable solutions HPUE
Government role	Procurement authority Service operator	Procurement authority	Procurement authority Responsible for services	Procurement authority Project management	Procurement authority FirstNet Authority
MNOs	Elisa	Orange, Bouygues Telecom	Korea Telecom, SK Telecom	EE (British Telecom Group)	AT&T
MNO's role	MC RAN services No core network services (MOCN)	MC RAN services Lower-core network services (full-MVNO model)	PS-LTE: Deployment and maintenance of LTE network and operation centres KT in charge of two districts, SKT in charge of one	MC RAN services Core network services	End-to-end public safety services, devices, applications, etc.
Competition	No competition	No competition	No competition	No competition	Open competition
MNO contract	10 years	4 + 3 years (option)	Until 2025	Until 2024	25 years, public–private partnership
Migration strategy	Migration from Virve (TETRA) to Virve 2.0 by 2025	Migration from Tetrapol networks to RRF by 2025	Migration from different networks to Safe-Net	Migration from Airwave network to ESN by 2026	No general plan, agencies make their own decisions

between agencies, and networks were congested due to the large number of calls. The report recommended the establishment of a national public safety network. In 2012, the FirstNet Authority was established within the Department of Commerce's National Telecommunications and Information Administration. The FirstNet Authority was given the responsibility of implementing, operating, and maintaining the network. In 2017, the MNO AT&T was awarded a public–private partnership contract to build and maintain FirstNet (FirstNet Authority, 2021).

3.7.2. Network configuration

The FirstNet service is based on AT&T's LTE network, complemented by LTE band 14, with 2 × 10 MHz in the 700 MHz band. The building of the new band is prioritised in rural areas to extend the geographical coverage of the network. An additional benefit of band 14 is the capability to use *high-power user equipment* (HPUE), as defined by 3GPP specifications. With HPUE, coverage can be improved, including indoor coverage. AT&T's regular customers can also use band 14 services, thus improving AT&T's overall ability to serve its customers. QPP functionalities are used for prioritised public safety services. An additional FirstNet coverage solution is deployable networks, including vehicles with satellite connections and drones that provide connectivity services. Public safety users are provided with their own core network, which isolates them from AT&T's regular users, improving security and resilience (FirstNet Authority,

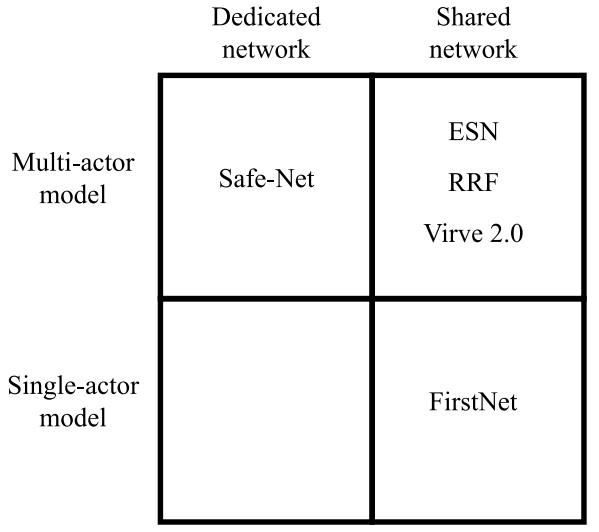

Fig. 2. Positions of the reviewed projects on the business model map.

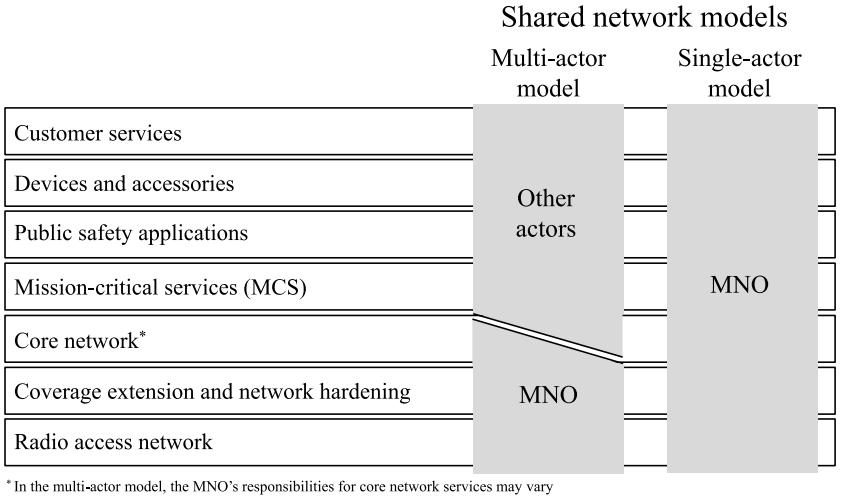

Fig. 3. Division of responsibilities of the reviewed projects in shared network business models.

2020a; AT&T, 2021).

3.7.3. Business model

AT&T has a 25-year public–private partnership contract with the FirstNet Authority to build and maintain the FirstNet network. As part of the transaction, AT&T received 20 MHz of radio spectrum and funding from the federal government, totalling 6.5 billion USD for the initial network rollout. In exchange, AT&T will invest 40 billion USD in the network in the next 25 years. The business model is the single-actor shared-network model. AT&T is completely in charge of FirstNet offerings, including end-to-end public safety services, devices, applications, customer services, and other related activities, such as sales and marketing (FirstNet Authority, 2020a).

AT&T has used its existing assets and made new investments in the FirstNet channel and ecosystem. AT&T has more than 5300 retail stores available for FirstNet customers (AT&T, 2018b). AT&T has complemented these with the FirstNet dealer programme (AT&T, 2018a), the FirstNet online portal (FirstNet, 2021c), 24/7 customer support, and the security operations centre (FirstNet Authority, 2020a). AT&T also provides FirstNet customers with approved devices and accessories (FirstNet, 2021d), MCS applications (FirstNet, 2021b), and public safety applications developed and certified under the FirstNet developer programme (FirstNet Authority, 2020b).

The United States public safety market has its own characteristics that affect AT&T's FirstNet business. In the United States, all public safety agencies can make their own decisions on the communications solutions they use. Despite 56 states and territories having

opted to accept FirstNet (FirstNet Authority, 2021), the market is open to competition; agencies do not have to choose FirstNet services. For example, AT&T's competitor Verizon markets its own public safety services under the name Verizon Frontline (Verizon, 2022). However, AT&T has priced FirstNet services to be competitive in the market; prices are comparable to AT&T's consumer services, although FirstNet provides prioritised services to public safety users[8] (AT&T, 2022; FirstNet, 2021a).

Another important characteristic of the United States market is its migration strategy. FirstNet does not immediately replace existing LMR networks, but it is an additional service that adds broadband data capabilities (Darrand, 2020). This makes the deployment of FirstNet services much easier when the migration plan and technologies do not need to be ready from the start. Migration may take place gradually once the technologies have been found to be sufficiently mature, and the agencies have learned to use and adopt the new technology.

FirstNet network investments also bring added value to AT&T's regular customers. In its third quarter 2020 report, AT&T reported significant growth in mobile subscribers and an all-time low churn rate. The message from John Stankey, AT&T's CEO, was that the success was due to FirstNet's investments, and he further stated, 'That higher quality network has removed a reason for customers to leave, because they're satisfied with the service that they're getting' (Reardon, 2020).

3.7.4. Status

FirstNet services were launched in 2018, starting from a dedicated core network; since then, the services have been available to public safety users (FirstNet Authority, 2021). According to AT&T, in December 2022, FirstNet had 4 million connections, users from more than 23,000 public safety agencies, and AT&T had completed 95% of the band 14 network implementations (FirstNet, 2022). There are about 3 million public safety users in the United States, and AT&T has been able to grow the number of connections well beyond this number (Atkinson, 2020). They have users they call the *extended community*, in addition to public safety users. There were also more than 525 FirstNet-compliant devices and over 200 FirstNet-certified apps (FirstNet, 2022). Additionally, FirstNet has 150 deployable network solutions, such as vehicles with satellite connections (FirstNet, 2022) and has introduced 5G to public safety users in selected cities and areas (FirstNet Authority, 2022).

4. Business model analysis

4.1. Projects selected for business model analysis

The selected projects for in-depth analysis are FirstNet in the United States and ESN in the United Kingdom. They represent different business models. In the FirstNet project, the business model is the single-actor shared-network model, and AT&T provides all public safety communications services and devices. In the ESN project, the business model is the multi-actor shared-network model, and EE provides MC RAN services, including core network services.

The ESN project represents a European model that three of the five reviewed projects have adopted. It also has the longest history of all the projects. Therefore, it is a natural choice for the business model analysis. FirstNet is based on a dedicated network like ESN, but the single-actor model is different from the ESN model. By changing only one dimension of the business model, the variation can be controlled and thus make the analysis of the results more robust. This follows Eisenhardt's (1989) case selection criterion.

By analysing these two business models, their similarities and differences can be identified. This helps to reveal the general characteristics of the models, and the business model comparison is the basis for drawing general conclusions (Eisenhardt, 1989).

4.2. ESN

Fig. 4 is a representation of the business model of the ESN project using the Casadesus-Masanell and Ricart framework. An introduction to the framework is presented in Section 2.2.

The model is divided into three different areas, depending on the ESN project actors. The MNO is in charge of one area and several other actors of another, covering public safety solutions, devices, and additional coverage solutions. All actors are jointly in charge of the third area, the area of joint interest. In this model, MNO refers to EE.

Once contracted for the ESN, the MNO is committed to significant investments to extend coverage and improve the resilience of the radio network (TED, 2019b). These are needed for the services to meet the needs of public safety users. MC RAN services, especially extended coverage, are also valuable to the MNO's regular customers. Therefore, the MNO also offers extended coverage to its regular customers and uses good coverage in its marketing (EE, 2021a). The goal is to increase the MNO's market share and increase the number of regular users. Improved services may also reduce churn, that is, the proportion of users leaving the MNO and switching to a competitor. All of this will contribute to the MNO's profits and reinvestment in the mobile business. It is important to note that the potential competitive advantage in the MNO's regular market is not necessarily sustainable and depends on the actions of its competitors.

Many other actors provide other offerings needed for public safety services. These include public safety solutions, devices designed for public safety, and additional coverage solutions, such as extended area services, London Underground coverage, and air-to-ground.

[8] Price comparison 14 March 2022: FirstNet Smartphone Plan, unlimited talk, text and data 39.99 USD/month; AT&T Unlimited Extra Plan, unlimited talk, text and data 40.00 USD/month with four lines, if more/fewer lines, the price is less/more per line. However, the content of the plans is not identical.

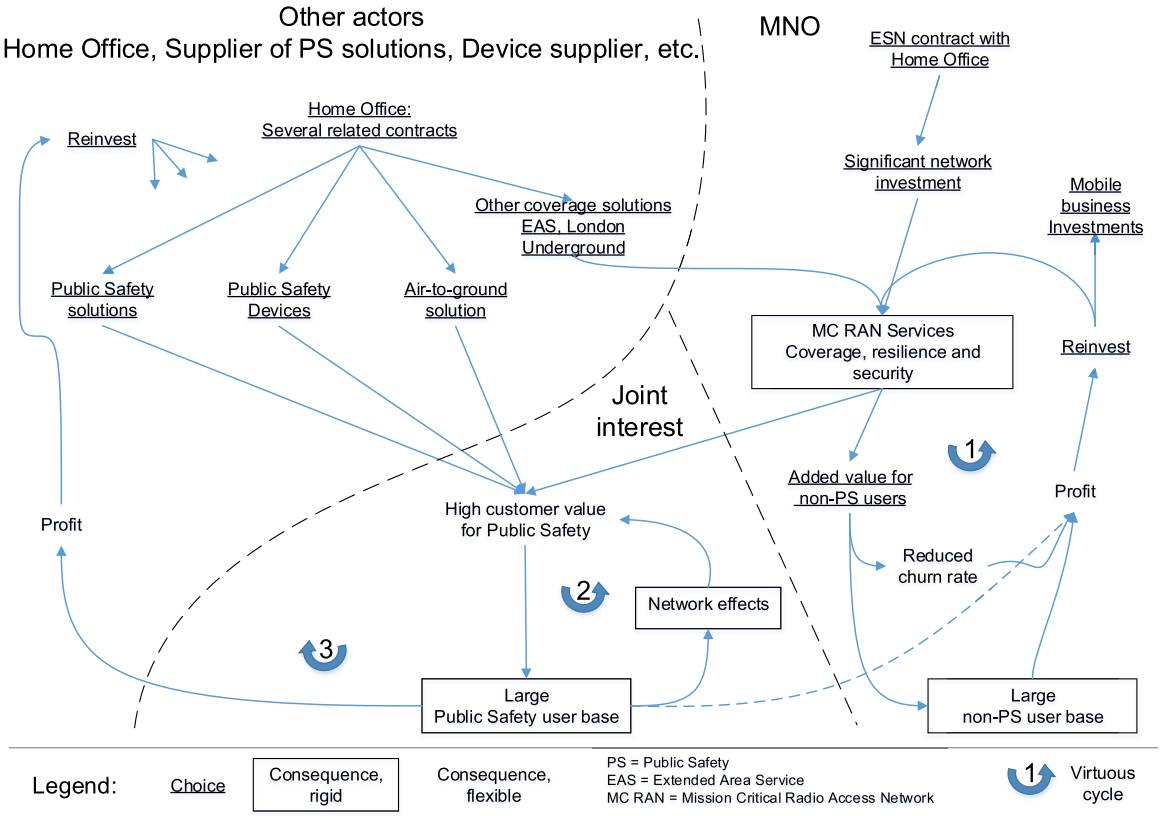

Fig. 4. ESN business model.

These are separate sub-projects launched by the Home Office.

The MNO's MC RAN services and the offerings of other actors are both needed for comprehensive public safety communications services. When all elements are in place, they provide high customer value, as illustrated by the joint interest area. Without all these elements, the services will not meet the needs of public safety users, and users will not migrate from the existing narrowband network to the new ESN. Therefore, all actors must work together.

In the ESN business model, three virtuous cycles can be identified. The first cycle is in the MNO area where extended coverage of MC RAN services adds value to the MNO's regular users, reduces churn, and contributes to the MNO's user base. A large user base creates profits and enables reinvestment in MC RAN services (and MNO's regular mobile business), starting the cycle again. The second cycle can be found in the area of joint interest, where high customer value for public safety users increases the public safety user base. Additional users increase network effects and add high customer value to public safety users, starting the cycle again. In the third cycle, the public safety user base creates profits that enable reinvestment in the offering of other actors, which in turn contributes to high customer value and the public safety user base. While the ESN project is still in the implementation phase, virtuous cycles are a future opportunity for the MNO, and their real value will be confirmed in the future.

4.3. FirstNet

Fig. 5 is a representation of the FirstNet business model using the Casadesus-Masanell and Ricart framework. An introduction to the framework is presented in Section 2.2.

In the FirstNet model, the MNO is solely responsible for the public safety communications business and for end-to-end services. Naturally, there are many ecosystem and channel partners that the MNO has contracted with. In this model, MNO refers to AT&T.

Once contracted for the FirstNet network and services, the MNO is committed to significant network investments to extend coverage and capacity and improve network resilience and security (FirstNet Authority, 2020a). Extended network coverage is valuable to the MNO's regular customers, consumers, and enterprises, and the MNO also provides extended coverage to them. The goal is to increase the MNO's market share and number of regular users. Improved services may also reduce churn (Reardon, 2020). All of this contributes to the MNO's profits and reinvestment in the mobile business. As with EE and the ESN, it is important to note that the potential competitive advantage in the MNO's regular market is not necessarily sustainable and depends on the actions of its

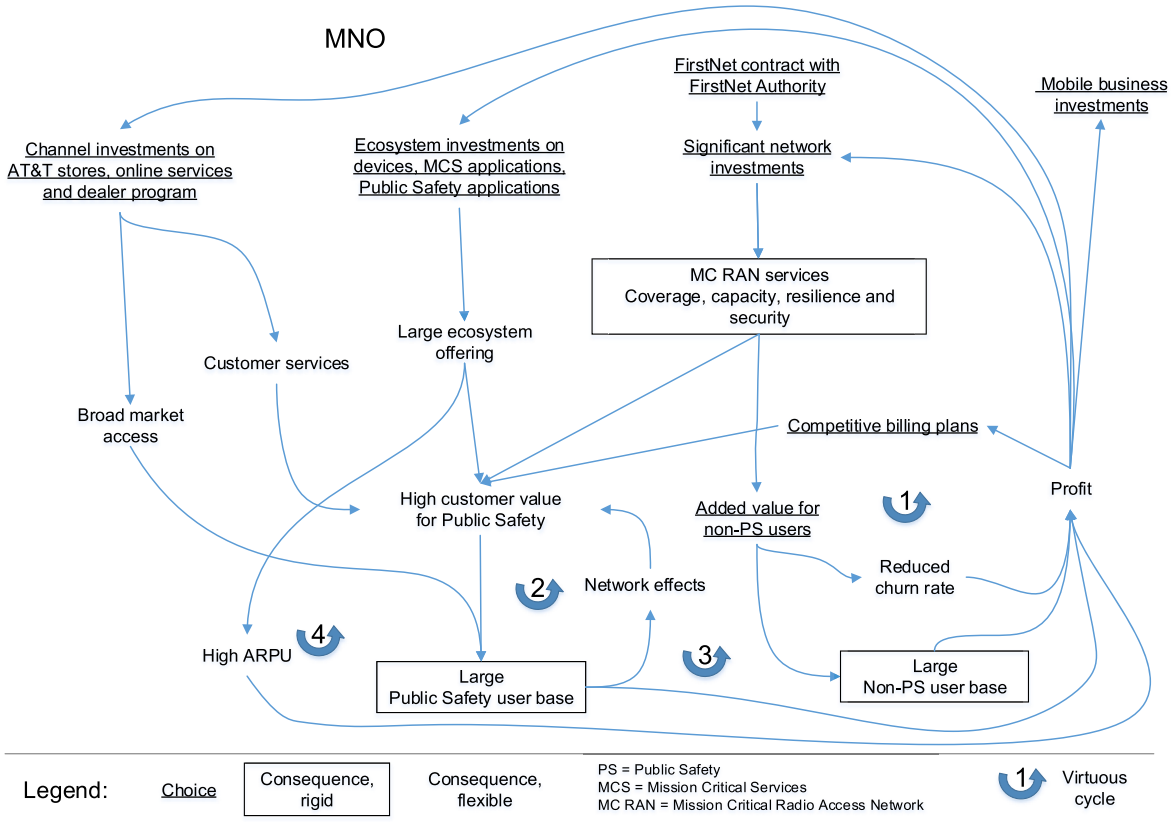

Fig. 5. FirstNet business model.

competitors, such as Verizon (see Section 3.7.3).

MC RAN services are essential for public safety users and are the basis for a comprehensive public safety offering, but other elements are also necessary. These include devices and accessories, and MCS and public safety applications. Channels for sales and customer service are also needed. The MNO can use some of the existing assets that it possesses due to its regular business, such as AT&T stores and partnerships with device suppliers, but investments in ecosystem offerings and channels, such as FirstNet developer and dealer programmes, are also needed.

All the different elements of the offering together – MC RAN services, devices, MCS and public safety applications, and customer service – provide high customer value to public safety users. This is also supported by competitive service prices. The MNO handles all of these elements, either directly or through contracts with its partners. This enables the MNO to manage end-to-end public safety services, as all service elements are under the control of the MNO. All the necessary public safety communication service elements at a competitive price contribute to a large public safety user base. A wide offering also contributes to high average revenue per user (ARPU).

In the FirstNet business model, four virtuous cycles can be identified. The first cycle is where MC RAN services (extended coverage) add value to the MNO's regular customers, reduce churn, and contribute to the MNO's user base, which creates profits and enables business reinvestment, starting the cycle again. In the second cycle, high customer value for public safety users contributes to the large public safety user base. Additional users increase network effects and add high customer value to public safety users, starting the cycle again. In the third cycle, the large public safety user base creates profits that enable reinvestment in the networks, ecosystem, and channels, which again contributes to high customer value and to the public safety user base. The fourth cycle is a sub-cycle of the third cycle. It is the creation of high ARPU due to the large ecosystem offering. The high ARPU contributes to high profits that enable reinvestment in the ecosystem, which in turn enables the large ecosystem offering.

There is some evidence of the value of virtuous cycles for the MNO. AT&T has stated that a higher-quality network has positively affected its market share and churn in the mobile services market (Reardon, 2020), hence following the logic of the first virtuous cycle. During the first five years of AT&T's FirstNet contract, the MNO has paid FirstNet Authority 120 million USD in annual payments, most of which is expected to be reinvested in the FirstNet network (Jackson, 2022), thus following the logic of the third virtuous cycle. AT&T has reached four million FirstNet connections in a relatively short period (FirstNet, 2022). A partial explanation is increased network effects according to the second virtuous cycle. To accurately assess the value of virtuous cycles, there should be open access to the MNO's financial figures. When this is not available, assessments are indicative only.

4.4. MNO business model comparison

This section compares the MNO business models between the FirstNet and ESN projects using the Osterwalder and Pigneur business model canvas (see Table 2) and the results of the ESN and FirstNet business model analyses in the previous sections. The business model canvas describes the characteristics of the business model from the perspective of the MNO, not the entire project. For example, key partners refer to the MNO's partners only, not partners of other actors in the project. Table 2 does not use the business model canvas template, but instead, a table format is used. However, the names of the business model components and their interpretations are the same as on the business model canvas.

The ESN's business model is the multi-actor shared-network model, and FirstNet's model is the single-actor shared-network model; in the following they are simply called multi-actor and single-actor models. The aim of the comparison is to look beyond the existing implementations of the models – that is, the individual projects. For example, in the United Kingdom, public safety agencies are ESN users by default, while in the United States, agencies can decide whether to use FirstNet services. Here, market differences and their implications are not characteristics of the business models but of the individual projects, although it may be challenging to distinguish between the implications of the business model and the market configuration.

The major difference between the multi-actor and single-actor models is the different positions of the MNO in the value chain. In the multi-actor model, the MNO does not manage the customer relationship with public safety agencies, as in the single-actor model. The value proposition is also distinctive. In the multi-actor model, the MNO provides only MC RAN services as wholesale, while in the single-actor model, the MNO handles the complete provision to users of public safety communications. Naturally, the required channel solutions are also different. In the multi-actor model, the MNO needs only straightforward account management for sales because there is only one customer. In the ESN, this is the Home Office. The single-actor model requires that channel solutions reach all public safety agencies. For example, AT&T has direct, indirect, and online channels, including an extensive network of physical stores (see Section 3.7.3).

The business models also differ in terms of revenue opportunities. In the multi-actor model, the MNO only receives revenue from wholesale MC RAN services, while in the single-actor model, the MNO's revenue sources are devices and accessories, MCS, and public safety applications, in addition to MC RAN services. In the single-actor model, MC RAN services can be sold in a subscription model that provides an opportunity for a higher margin than in the wholesale model. Additionally, because the MNO manages the customer relationships of public safety agencies, new innovative offerings can be created over time.

Due to the extended coverage, both business models provide the MNO with the opportunity to increase the market share in the regular customer segment and reduce churn. Extended network coverage, high availability, and security may also be required from other industries, which offers the MNO an opportunity to enter a new market. However, this depends on the strategy of the MNO.

FirstNet's long 25-year contract period and the public–private partnership contract are elements that are expected to have a positive impact on investments and innovations (Roumboutsos & Saussier, 2014). Innovations, in turn, are a source of new revenue and improved margins. Here, a long contract period and a public–private partnership contract are not characteristics of the single-actor model, although it supports them. Long contract periods are typical in public–private partnerships, which enables significant infrastructure investments that often occur in these projects. In the FirstNet project, there is still no evidence of the long contract period's positive impact on investments and innovations, the operational phase of the project has only lasted since 2018 (Section 3.7.4).

In terms of key activities, resources, and partners, there is a similar pattern between the two models as in other business model areas. In both business models, the assets related to the radio network are the same, including the network itself, with data centres, deployment, and maintenance of the network infrastructure, network operations, and telecommunication equipment suppliers as key partners. The single-actor model also requires many other assets. Key activities in the single-actor model include sales and marketing, service and device management, and channel and partnership management. IT systems are also needed to manage customers, services, and devices. Additional partners include device suppliers and application developers. Many of the additional assets of the single-actor model are such that the MNO may already have them in some form, such as sales and marketing, customer and service management systems, and partnerships with device suppliers. On the other hand, completely new assets may also be needed, including channel and application ecosystem partners.

The significant cost in both business models is investment in the radio network.[9] For MC RAN services, network coverage needs to be extended and resilience and security hardened. The single-actor model also has other costs, including IT solutions for customer, service and device management, personnel costs for sales and marketing, customer support, and partnership management. The single-actor model has the potential to leverage the MNO's existing assets, and thus, the synergies between regular and public safety customers can reduce additional costs. For example, the MNO's existing channels can also be used for public safety sales and marketing.

The virtuous cycles addressed in the individual business model analysis of both projects have both similarities and differences. The cycle in which the extended coverage of MC RAN services adds value to the MNO's regular users, reduces churn, and contributes to the MNO's regular user base is the same in both projects. The same applies to the cycle where high customer value for public safety users

[9] This estimation demonstrates the share of network investment in FirstNet over the 25-year contract period. Assume that the number of FirstNet users is three million (Section 3.7.1) and the average monthly ARPU is 100 USD (see footnote 8, Section 3.7.3). During the contract period, this will generate 90 billion USD in revenue. AT&T has estimated it will invest approximately 40 billion USD in the network during the contract period (FirstNet Authority, 2017). In this estimation, the investment accounts for 44% of the revenue. Note that AT&T's goal is to get not only public safety customers but also customers from the extended community. Additional revenue due to potential market share growth and reduced churn in the mobile market are also not included.

Table 2
Comparison of MNO business models used in the FirstNet and ESN projects.

	FirstNet	ESN
Business model	Single-actor shared network	Multi-actor shared network
Value proposition	MC RAN services; nationwide upgraded coverage and capacity (B14); devices and accessories for first responders; MCS and public safety applications; related customer services	MC RAN services; nationwide upgraded coverage
Customer segments	1) Public safety agencies in the US 2) Extended community, such as healthcare, transportation, and utilities	Contract with: The Home Office Users: Public safety users in the UK
Customer relationships	The FirstNet user community is supported in many ways, such as events, webinars, blogs, news, videos, and FirstNet newsletter	Business-to-Government, one customer (the Home Office)
Key activities	Deployment and maintenance of network infrastructure; network operations; sales and marketing; service and device management; channel management; partnership management	Deployment and maintenance of network infrastructure; network operations
Key resources	Mobile network infrastructure; data centres; customer relationship and service management systems; ecosystem partnerships; public–private partnership contract with FirstNet Authority	Mobile network infrastructure; data centres; the Home Office contract
Key partners	Telecommunication equipment suppliers; device suppliers; application partners; FirstNet Authority	Telecommunications equipment suppliers
Channels	FirstNet online services; AT&T stores; FirstNet customer support centres; FirstNet dealer programme for valued-added resellers	Wholesale through the Home Office
Cost structure	Network investments; network maintenance; cost of data centres including personnel; IT solutions for customer relationship, service, and device management; personnel for sales and marketing, customer support, and partnership management	Network investments; network maintenance; cost of data centres including personnel
Revenue streams	Subscription fees; devices and accessories; MCS and public safety applications; contract payment from FirstNet Authority; opportunity to increase market share in the regular customer segment and reduce churn; new innovations over time	Contract payment from Home Office; opportunity to increase market share in the regular customer segment and reduce churn

contributes to the public safety user base, and additional users increase network effects. The third virtuous cycle, which is rooted in the large public safety user base and the profit it creates, is different. In the single-actor model, profit enables reinvestment in the network, ecosystem, and channels, which in turn contributes to high customer value. Therefore, the MNO has a strong incentive to continuously invest in public safety services. This is not the case with the multi-actor model. The large public safety user base creates the ability to invest in related projects but not in MNO's services. This is because the MNO does not invoice public safety users for MC RAN services, or the invoicing is relatively small. For this reason, there is no incentive for the MNO to reinvest in MC RAN services. Of course, there may be other incentives, such as rewards or penalties, based on a service-level agreement.

The control of the value delivered to public safety customers is another aspect that deserves attention when comparing business models. In the single-actor model, the MNO fully controls customer value and all necessary elements of public safety communications. For the MNO, this is an opportunity. By taking care of all service elements, it can deliver high customer value when needed. The multi-actor model is very different. The MNO only controls MC RAN services, and other actors control other elements. Even if the MNO could deliver its service completely, but some other necessary service element is missing, the value received by the customer would be zero. This is a risk that the MNO must consider in its business plan.

5. Discussion

This discussion first summarises the research findings of the business model comparison. Then, two compared business models are addressed from three perspectives: 1) What is the progress of practical projects? 2) What are the strategic objectives that affect the procurement authority's business model selection? 3) How should the MNO evaluate the business model and other project topics?

In this research, a review of nationwide public safety mobile broadband projects revealed different MNO business models. The multi-actor and single-actor shared-network business models were analysed and compared. Both models are based on sharing the MNO's radio access network between public safety users and the MNO's regular customers. MNOs can meet public safety requirements by extending the network coverage, hardening the network for resilience and security, and prioritising public safety users.

The major difference between the multi-actor and single-actor models is the MNOs' different positions in the value chain, which affects the MNOs' business opportunities. In the multi-actor model, the MNO only provides wholesale MC RAN services, and revenue opportunities are limited. In the single-actor model, the MNO provides all the necessary services and devices for public safety communications, including applications, and the MNO controls the delivered end-to-end value. These different offering elements increase revenue potential. The MNO also has the opportunity for innovation and thereby new offerings and revenue. The advantage of both business models is the extended network coverage for MNOs' regular customers, which offers an opportunity to increase market share and reduce churn in the mobile market.

The resources required are also different in the business models. Both models need significant network investment to meet public safety needs, but the single-actor model also requires ecosystem and channel investments.

Next, the progress of practical projects is discussed. The FirstNet project, which follows the single-actor model, has made good progress. AT&T was awarded the FirstNet project in 2017 (FirstNet Authority, 2021). In December 2022, FirstNet had 4 million connections and 23,000 public safety agencies using the services. Progress has also been good in other areas, such as band 14 implementation (95%), number of FirstNet-compliant devices (525), and FirstNet-certified apps (200; FirstNet, 2022). EE was originally awarded the ESN contract in December 2015 (TED, 2019b). As of the spring of 2022, the project is still in the implementation phase, and the target is to start the migration of users to the ESN in 2024, with the goal of completion in 2026 (Jackson, 2021).

Great care must be taken before drawing hasty conclusions about business models based on the progress of two projects that are different in many ways. The structure of multi-actor model can pose challenges for project management, and therefore the responsibility for system integration needs to be clear. This was also stated by the National Audit Office (2019) in its ESN progress report; the responsibility for end-to-end integration was unclear and caused delays. However, the market structures are different in the FirstNet and ESN projects. In the United States, the market is fragmented and based on open competition; in the United Kingdom, it is government driven. Migration requirements are also different in the two projects. The goal of the FirstNet project is not to replace LMR services immediately; it is an additional service without an immediate migration requirement. This facilitates the deployment of FirstNet services. The ESN, on the other hand, aims to replace the existing Airwave services. This requires integration with control rooms, Airwave services, and other existing solutions, which makes the ESN's technical migration requirements challenging.

The next topic is the procurement authority's strategic objectives affecting business model selection. Two different objectives are discussed, which can be identified behind the decisions of the reviewed projects. A procurement authority may have these and other strategic objectives, each with its own weight in decision making.

One identified strategic objective is the need to protect confidential information. In the European Virve 2.0 and RRF projects, this is one of the reasons for choosing the multi-actor shared-network model (Melkko, 2021; Carmona, 2021). This question was also raised in a report by the Norwegian Directorate for Civil Protection (2018). If the government has full control over the core network, it can control sensitive user data, such as location information. In practice, this requires a government-controlled service operator. If the MNO provides MC RAN services, the result is the multi-actor shared-network model.

Another identified strategic objective of the procurement authority is minimising the role of the public sector. This objective can be translated into several goals that can be achieved through public–private partnerships: 1) minimising the need for taxpayers' money and using private funding for the project, 2) transferring risk from the public to the private sector, 3) efficient service delivery, and 4) support for innovations (World Bank, 2017). The single-actor shared-network business model is well suited to public–private partnerships, as there is only one party with operational and business responsibilities. These goals are also among the reasons why the FirstNet Authority chose the public–private partnership with AT&T (FirstNet Authority, 2017), and this led to single-actor

shared-network business model.

A suggestion for practical projects for decision making between business models is to specify strategic objectives and evaluate the models based on them. Two examples of strategic objectives were discussed above. If no clear criteria can be found for the choice of either model, a simpler single-actor shared-network model with only one actor is justified.

For an MNO, the business model is usually provided in public tender, and the MNO cannot choose the model but must assess the available business opportunity. The strategic fit of the given business model for the MNO depends on the MNO's business strategy. If the MNO's strategy is to address the vertical market of public safety organisations with a comprehensive offering, the single-actor shared-network model is likely to provide a good strategic fit. Another potential business strategy is to address a horizontal market of different industries, with a demand for wide network coverage and high availability and security. In addition to public safety, another example is the smart grid market, driven by decentralised renewable electricity generation (Leligou et al., 2018). The horizontal market strategy enables the MNO to focus on general offerings for several industries. The multi-actor shared-network model provides a good fit for the horizontal market strategy. Vertical and horizontal strategies are not mutually exclusive but can be mixed.

The challenge for the MNO is the relatively small number of public safety users and demanding requirements that entail significant network investment. The MNO should have a clear view of the investment required and its financing. For example, what is the share of the investment paid by the procurement authority. The MNO should also estimate the impact of network investment on the regular mobile market. The MNO may gain a competitive advantage, or, in the worst case, one of its competitors may win the project, and its relative position in the market may improve.

The MNO should also evaluate the project organisation if the multi-actor shared-network model with several project actors is followed. The role of the system integrator is essential to the project. The integrator should have technical expertise, and the project management structure should support the integrator's authority. Finally, the length of the contract period and the contract type also deserve the MNO's attention. A long contract period combined with a public–private partnership contract is expected to support investments and innovations (Roumboutsos & Saussier, 2014).

Table 3 summarises the key conclusions of the comparison of the two shared-network business models.

6. Conclusion

The results show that MNOs have new business opportunities in the public safety market as agencies move from narrowband to 4G/5G broadband technologies. MNOs' existing mobile networks can be used for public safety services with certain enhancements. There are different business models for MNOs in existing projects, and none of these models has achieved a clearly dominant position. It is likely that there will also be projects with different business models in the future.

Two of the business models, the multi-actor shared-network model and the single-actor shared-network model, were analysed and compared. The single-actor model offers the MNO a higher revenue opportunity than the multi-actor model, but the MNO needs to have more resources for the single-actor model, including ecosystem and channel investments. However, the model also offers an opportunity for innovation and thus new offerings and revenue. In both business models, the MNO can take advantage of the extended network coverage with regular customers, providing an opportunity to increase market share and reduce churn in the mobile market.

The suitability of the business models depends on the MNO's business strategy. The single-actor business model has a good fit with the vertical market strategy, in which the MNO targets the vertical market for public safety services with a comprehensive offering. The multi-actor model fits well with the horizontal market strategy, as the MNO addresses several industries with similar service requirements in terms of extended coverage, high availability, and security. These two business strategies can also be mixed.

Usually, the business model is provided to the MNO in a public tender. The MNO must evaluate the business model in relation to its business strategy. In addition, this research suggests that the MNO should also evaluate a few other topics. Financing the investment to

Table 3
Key conclusions of the comparison of the shared-network business models.

ID	Description	Single-actor shared network	Multi-actor shared network
	Key characteristics of the business model		
1	MNO manages the customer relationship with public safety agencies	✔	
2	MNO controls the delivered end-to-end customer value	✔	
3	Wholesale of MC RAN services		✔
4	The role of the integrator is essential		✔
	MNO's business opportunities		
5	Versatile offering – high revenue potential	✔	
6	MNO delivers only MC RAN services		✔
7	Extended coverage and improved resilience are opportunities in the mobile market	✔	✔
8	Opportunity for business innovations	✔	(✔)
	MNO's investments		
9	Significant investments on network coverage and hardening	✔	✔
10	Ecosystem and channel investments needed	✔	
	MNO's strategy		
11	Good fit with the MNO's vertical market strategy	✔	
12	Good fit with the MNO's horizontal market strategy		✔

extend and harden the network is one of the topics. Another topic is the impact on the mobile services market. The extended network coverage may give the MNO a competitive advantage in the mobile market. On the other hand, if one of MNO's competitors is awarded the project, it may gain a competitive advantage in the market. The third topic is the responsibility for the end-to-end integration in the projects following the multi-actor model; the integration responsibility should be clear and well defined. The fourth topic concerns the length of the contract period, especially for single-actor projects. In public–private partnership projects, a long contract period is expected to support investments and innovations.

For the procurement authorities, this research suggests assessing the appropriate business model based on strategic objectives. The research identified two different objectives; the need to protect confidential information and the target to minimise the role of the public sector. Procurement authorities may also have other strategic objectives.

This research brings new knowledge about existing next-generation public safety projects and their business models, as well as MNOs' new business opportunities in the public safety market. There is very little previous research on the subject; therefore, this paper lays the groundwork for new research. The results of this paper can also be used in practical projects by procurement authorities and MNOs.

This research is based on only five projects, of which only two are in the production phase. Overall, the migration of public safety agencies to broadband technologies is in its infancy. New projects and new knowledge enable further research to validate the results and expand the research topic.

Research funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of interest

Tapio Savunen works at Airbus Defence and Space, in the Secure Land Communications business; Heikki Hämmäinen, none;Kalevi Kilkki, none; Pekka Kekolahti, none

Acknowledgements

The authors would like to thank Dr. Matti Peltola and Dr. Jaakko Saijonmaa for their valuable comments.

References

3 rd Generation Partnership Project [3GPP]. (2020). *3GPP ts 23.251 V16.0.0.* ; Technical specification group services and system aspects; Network sharing; Architecture and functional description (Release 16) https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=830.

Airwave. (2022). *Emergency services network*. https://www.airwavesolutions.co.uk/the-service/emergency-services-network/.

AT&T. (2018a). *FirstNet launches dealer program, making it even easier for public safety agencies to access their network*. https://about.att.com/story/firstnet_dealer_program.html.

AT&T. (2018b). *AT&T retail stores across the country open doors to verified first responders for FirstNet service*. https://pacificregion.att.com/at-t-retail-stores-across-the-country-open-doors-to-verified-first-responders-for-firstnet-service/.

AT&T. (2021). *FirstNet MegaRange: Extending first responder connectivity like never before*. https://about.att.com/newsroom/2021/fn_megarange.html.

AT&T. (2022). *Compare our wireless plans*. https://www.att.com/plans/wireless/.

Atkinson, J. (2020). *US public safety LTE networks. Critical Communications Today*. https://www.criticalcomms.com/features/us-public-safety-lte-networks.

BAI C.ommunications. (2021). *Bai communications awarded 20-year concession to deliver high-speed mobile coverage across the London Underground. Bai Communications*. https://www.baicommunications.com/mediarelease/bai-communications-awarded-20-year-concession-to-deliver-high-speed-mobile-coverage-across-the-london-underground/.

Carmona, G. (2021). *Réseau radio du Futur program, status update for TCCA*. https://tcca.info/documents/France-Broadband-update_Gerard-Carmona.pdf.

Casadesus-Masanell, R., & Ricart, J. E. (2010). From strategy to business models and onto tactics. *Long Range Planning, 43*(2–3), 195–215.

Chinta, K., Kirui, A., & Hook, F. (2019). *UAE's Nedaa adopts Nokia's private LTE for Safe and Smart City Applications - leveraging mobile broadband to coordinate public safety and security*. IDC.

Cho, M. H. (2021). *Samsung completes nationwide public safety network in South Korea*. ZDNet. https://www.zdnet.com/article/samsung-completes-nationwide-public-safety-network-in-south-korea/.

Clark, L. (2021). Samsung gets 2-year contract extensions to provide rugged handsets for UK's troubled Emergency Services Network. The Register https://www.theregister.com/2021/12/16/samsung_esn_extension/.

Critical Comms. (2021). *Feasibility trial for public safety program*. Critical Comms https://www.criticalcomms.com.au/content/public-safety/news/feasibility-trial-for-public-safety-program-914806619.

Copeland, R., & Crespi, N. (2011). Modelling multi-MNO business for MVNOs in their evolution to LTE, VoLTE & advanced policy. *15th international conference on intelligence in next generation networks, IEEE*, 295–300, 4–7 October 2011.

Darrand, R. (2020). *Licensed mobile radio terminals report – 2019*. IHS Markit.

Donkin, C. (2022). *Orange, Bouygues among emergency network winners. Mobile World Live*. https://www.mobileworldlive.com/featured-content/top-three/orange-bouygues-among-emergency-network-winners/.

EE. (2021a). The UK's No. 1 4G network gets even better. *EE Large Business*. https://business.ee.co.uk/large-business/esn/esn-ee/.

EE. (2021b). *ESN coverage extender from EE*. EE Large Business. https://business.ee.co.uk/large-business/esn/temporary-coverage/.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review, 14*(4), 532–550.

Elisa. (2020). *Elisa valittiin uuden viranomaisverkko Virven ainoaksi radioverkkotoimittajaksi 10 vuodeksi laadun ja kattavuuden ansiosta*. https://elisa.fi/yhtiotieto/uutishuone/tiedotteet/elisa-valittiin-uuden-viranomaisverkko-virven-ainoaksi-radioverkkotoimittajaksi-10-vuodeksi-laadun-ja-kattavuuden-ansiosta/04566655363560/.

Ericsson. (2020). *Remote Faroe Islands lead the way in public safety networks with Ericsson solution*. https://www.ericsson.com/en/news/2020/11/remote-faroe-islands-get-ericsson-public-safety-solution.

Erillisverkot. (2021a). *Näin Virvestä kasvoi Suomen turvallisuusekosysteemin tukijalka – jo yli 51 000 liittymää*. https://www.erillisverkot.fi/nain-virvesta-kasvoi-suomen-turvallisuusekosysteemin-tukijalka-jo-yli-51-000-liittymaa/.

Erillisverkot. (2021b). *Erillisverkot vuosikertomus 2020*. https://www.erillisverkot.fi/uploads/2021/04/erillisverkot-vuosikertomus-2020.pdf.
Erillisverkot. (2021c). *Virve 2.0 mobile strategy, building safety together*. Erillisverkot https://www.erillisverkot.fi/uploads/2021/04/virve-mobile-stragegy-2021-version-1.1_03_2021web.pdf.
Euchner, J., & Ganguly, A. (2014). Business model innovation in practice. *Research-Technology Management, 57*(6), 33–39.
Fantacci, R., Gei, F., Marabissi, D., & Micciullo, L. (2016). Public safety networks evolution toward broadband: Sharing infrastructures and spectrum with commercial systems. *IEEE Communications Magazine, 54*(4), 24–30.
Fenwick, S. (2019). France's push for public safety broadband. *Critical Communications Today*. https://www.criticalcomms.com/features/france-ppdr-broadband-rrf-pcstorm.
FirstNet. (2021a). *Rate plans*. https://www.firstnet.com/plans.html?tabs=26b46e66-b7ba-4c26-9bf8-63f88b12fb29.
FirstNet. (2021b). *FirstNet PTT: Mission-ready push-to-talk*. https://www.firstnet.com/mission-critical/firstnet-push-to-talk.html.
FirstNet. (2021c). *FirstNet central*. https://www.firstnet.com/apps/firstnet-central.html.
FirstNet. (2021d). *Devices & accessories*. https://www.firstnet.com/devices.html.
FirstNet. (2022). *FirstNet by the numbers*. https://www.firstnet.com/content/dam/firstnet/white-papers/firstnet-by-the-numbers.pdf.
FirstNet Authority. (2017). *FirstNet partners with AT&T to build wireless broadband network for America's first responders*. https://2014-2018.firstnet.gov/news/firstnet-partners-att-build-wireless-broadband-network-americas-first-responders.
FirstNet Authority. (2020a). *FirstNet: The network*. https://www.firstnet.gov/network.
FirstNet Authority. (2020b). *FirstNet for developers*. https://www.firstnet.gov/network/TT/firstnet-for-developers.
FirstNet Authority. (2021). *FirstNet: The history of our nation's public safety network*. https://www.firstnet.gov/about/history.
FirstNet Authority. (2022). *FirstNet now covers more first responders than any network in the country*. https://www.firstnet.gov/newsroom/press-releases/firstnet-now-covers-more-first-responders-any-network-country.
Forge, S., Horvitz, R., & Blackman, C. (2014). *Is commercial cellular suitable for mission critical broadband. A study prepared for the European commission DG communications networks, content and technology*. SCF Associates LTD. European Union. https://data.europa.eu/doi/10.2759/54788.
Geissdoerfer, M., Savaget, P., & Evans, S. (2017). The Cambridge business model innovation process. *Procedia Manufacturing, 8*, 262–269.
Grous, A. (2013). *The socioeconomic value of mission critical mobile applications for public safety: 2x10MHz in 700MHz, preliminary research results: UK and EU*. London: Professional LTE Conference, 10 October 2013.
Hallahan, R., & Peha, J. M. (2013). Enabling public safety priority use of commercial wireless networks. *Homeland Security Affairs, 9*(13).
Hankintailmoitukset. (2019). *Virve 2.0; radioverkon (RAN) hankinta*. https://www.hankintailmoitukset.fi/en/public/procurement/16268/notice/18695/overview.
Hoffman, M.-L. (2015). *FirstNet board oks program's final RFP, eyes january bid solicitation. GovConWire*. https://www.govconwire.com/2015/12/firstnet-board-oks-programs-final-rfp-eyes-january-bid-solicitation/.
Home Office. (2021a). *Emergency services network: Overview*. GOV.UK https://www.gov.uk/government/publications/the-emergency-services-mobile-communications-programme/emergency-services-network.
Home Office. (2021b). About us – the first duty of the government is to keep citizens safe and the country secure. In *The Home Office plays a fundamental role in the security and economic prosperity of the UK*. GOV.UK. https://www.gov.uk/government/organisations/home-office/about.
Hong, Y. S. (2020). *South Korea finalizes first phase of public-safety LTE buildout*. RadioResource Media Group. https://www.rrmediagroup.com/Features/FeaturesDetails/FID/978.
Hong, Y. S., & Kim, D. C. (2019). Korea public safety mobile broadband project update. *Critical Communications World 2019*. https://critical-communications-world.com/media/16410/young-sam-hong-dong-chan-kim-korea-public-safety-mobile-brodband-project-update.pdf.
Höyhtyä, M., Lähetkangas, K., Suomalainen, J., Hoppari, M., Kujanpää, K., Ngo, Tero Kippola, Heikkilä, M., Posti, H., Mäki, J., Savunen, T., Hulkkonen, A., & Kokkinen, H. (2018). Critical communications over mobile operators' networks: 5G use cases enabled by licensed spectrum sharing, network slicing and QoS control. *IEEE Access, 6*, 73572–73582.
Hwang, S., & Kim, D. C. (2020, 22 October). *Korea Safe-Net update. TCCA Critical Communications Mobile Broadband Group Plenary Meeting #22*.
International Telecommunication Union [ITU]. (2022). *Mobile-cellular subscriptions 2000-2021. Statistics – country ICT data* (latest available data) https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx.
IWCE's Urgent Communications. (2013). UK seeks to replace TETRA with LTE as early as 2016. *IWCE's Urgent Communications*. https://urgentcomm.com/2013/06/06/uk-seeks-to-replace-tetra-with-lte-as-early-as-2016/.
Jackson, D. (2021). UK plans to start public-safety 'mass transition' from Airwave to ESN in first half of 2024. *IWCE's Urgent Communications*. https://urgentcomm.com/2021/10/15/uk-plans-to-start-public-safety-mass-transition-from-airwave-to-esn-in-first-half-of-2024/.
Jackson, D. (2022). FirstNet Authority board approves FY 2023 budget of $358 million. *IWCE's Urgent Communications*. https://urgentcomm.com/2022/08/18/firstnet-authority-board-approves-fy-2023-budget-of-358-million/.
Kim, D. C. (2021). *Korea Safe-Net update & case study*. Safe-Net Forum.
Lair, Y., & Mayer, G. (2017). *Mission critical services in 3GPP. 3GPP*. https://www.3gpp.org/news-events/1875-mc_services.
Laxdal, G. (2016). Number theories: What 100 operators really think about 5g. *Ericsson Business Review, 1*.
Leligou, H. C., Zahariadis, T., Sarakis, L., Tsampasis, E., Voulkidis, A., & Velivassaki, T. E. (2018). Smart grid: A demanding use case for 5G technologies. In *2018 IEEE international conference on pervasive computing and communications workshops (PerCom workshops)* (pp. 215–220). Athens, Greece, 19-23 March 2018.
Melkko, H. (2021). *Viranomaisverkkojen kehitys suomessa: Erot Virve ja Virve 2.0 verkkototeutusten välillä* [Bachelor's thesis, Tampere University] https://trepo.tuni.fi/bitstream/handle/10024/133149/MelkkoHeidi.pdf;jsessionid=8D54AB600D7A3DDD6BB89F628B0EA3BB?sequence=2.
Mellies, R. (2022). France broadband PPDR network: RRF status update. *TCCA Critical Communications Mobile Broadband Group Plenary Meeting #26, 4 November*.
MSB. (2021). *MSB tar nästa steg i storsatsning på ett modernt kommunikationssystem*. https://www.msb.se/sv/aktuellt/nyheter/2021/oktober/msb-tar-nasta-steg-i-storsatsning-pa-ett-modernt-kommunikationssystem/.
National Audit Office. (2019). *Progress delivering the Emergency Services Network*. https://www.nao.org.uk/wp-content/uploads/2019/05/Progress-delivering-the-Emergency-Services-Network.pdf.
Norwegian Directorate for Civil Protection. (2018). Alternatives for mission-critical services in public mobile networks in Norway. *Dsb Nødnett*. https://www.nodnett.no/bibliotek/alternatives-for-mission-critical-services-in-public-mobile-networks-in-norway/.
Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers* (Vol. 1). John Wiley & Sons.
Peltola, M., & Hämmäinen, H. (2018). Effect of population density and network availability on deployment of broadband PPDR mobile network service. *Digital Policy, Regulation and Governance, 20*(1), 78–96.
Productivity Commission. (2015). *Public safety mobile broadband*. Australian Government. https://www.pc.gov.au/inquiries/completed/public-safety-mobile-broadband/report.
RadioResource Media Group. (2022). *EE, Nokia to build air-to-ground network for ESN* https://www.rrmediagroup.com/News/NewsDetails/NewsID/21323.
Reardon, M. (2020). *AT&T's wireless business thrives amid pandemic*. CNET. 22 October 2020 https://www.cnet.com/tech/mobile/at-ts-wireless-business-thrives-amid-pandemic/.
Roumboutsos, A., & Saussier, S. (2014). Public-private partnerships and investments in innovation: The influence of the contractual arrangement. *Construction Management & Economics, 32*(4), 349–361.
Sánchez, P., & Ricart, J. E. (2010). Business model innovation and sources of value creation in low-income markets. *European Management Review, 7*(3), 138–154.
TCCA. (2018). *Critical communications and mobile network operators – Options for new revenue streams and new market segments*. https://tcca.info/documents/2018-may_critical_communications_mobile_network_operators.pdf/.
TED. (2019a). *Services - 2803898-2019* https://ted.europa.eu/udl?uri=TED:NOTICE:280398-2019:TEXT:EN:HTML.
TED. (2019b). *Services - 409374-2019* https://ted.europa.eu/udl?uri=TED:NOTICE:409374-2019:TEXT:EN:HTML.
TED. (2020). *Services - 586641-2020* https://ted.europa.eu/udl?uri=TED:NOTICE:586641-2020:TEXT:EN:HTML&src=0.

Tetrapol. (2022). *TETRAPOL references*. https://www.tetrapol.com/markets_and_trends/references/.
Verizon. (2022). *Verizon Frontline, the advanced network and technology for first responders*. https://www.verizon.com/business/solutions/public-sector/public-safety/.
Waring, J. (2018). *South Korea earmarks $1.6B for public safety network*. Mobile World Live https://www.mobileworldlive.com/asia/asia-news/south-korea-earmarks-1-6b-for-public-safety-network.
Wirtz, B. W., Pistoia, A., Ullrich, S., & Göttel, V. (2016). Business models: Origin, development and future research perspectives. *Long Range Planning, 49*(1), 36–54.
World Bank. (2017). *Public-private partnerships, reference guide*. World Bank Group. Version 3 https://elibrary.worldbank.org/doi/abs/10.1596/29052.
Yarali, A. (2020). *Public safety networks from LTE to 5G*. John Wiley & Sons.