Utilization of commercial mobile networks in the deployment of C-ITS services

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Finnish Transport and Communications Agency

The aim of this research was to study how well the commercial mobile **networks of today** can serve the estimated C-ITS data traffic **of the future**.

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Background

What are C-ITS services and why are they important?

- Cooperative Intelligent Transport Systems (C-ITS) means intelligent transport systems (ITS) that exchange **real-time** C-ITS messages with vehicles, other road users, infrastructure and other environment using **trusted** and **secured** communication.
- C-ITS services provide **safety** and **efficiency** benefits for road users by informing them about traffic situation and circumstances **in advance**.
- C-ITS messages are **signed messages** that are **defined by ETSI and ISO** and profiled in the **C-Roads.**

For more information see https://www.c-roads.eu/platform.html

What makes mobile networks desirable technology for the deployment of C-ITS services?

- Utilizing commercial mobile networks for C-ITS services **reduces public investment** needs as nationwide infrastructure already exists.
- Mobile network technologies are **constantly** developing by **market** demand, offering the needed capacity and coverage.
- Finland is a forerunner in mobile network technologies.
- **OEM carmakers** have confirmed their commitment towards the widespread adoption of C-V2X technology.

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How the study was conducted

1. C-ITS performance metrics & KPIs → **2. Service level framework for C-ITS services** → **3. 2030 C-ITS scenarios** → **4. Capacity estimates** → **5. C-ITS feasibility assessment**

1. C-ITS performance metrics & KPIs

C-ITS performance metrics together with telecommunication standardization metrics were analyzed to define **Key Performance Indicators** in order to find out what attributes to measure.

2. Service level framework for C-ITS services

Service level framework was established with the help of KPIs to understand the quality-of-service needs and level of operability.

3. 2030 C-ITS scenarios

Scenarios were defined to understand the **total capacity demand of C-ITS services**, taking into consideration variables such as traffic volume, message size, and update rate.

4. Capacity estimates

Mobile network capacity estimates describe the total **available** capacity.

5. C-ITS feasibility assessment

By comparing the C-ITS capacity **demand** to the available mobile network total **capacity** the C-ITS feasibility can be assessed.

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1. Selection of C-ITS-services for the study

- **Different types of services were selected** to the study
- Different services vary for example in terms of **message type** (size and frequency) and **logic of transmission** (downlink or uplink).

Selected C-ITS services

1. Temporarily slippery road
2. Road Works Warning
3. Signal Phase and Timing
4. Vehicle Data Collection
5. Collective Perception

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1. KPI categories and indicators

- *Key Performance Indicators (KPI)* are strategic metrics to **assess performance of the C-ITS services**. KPI parameters can be used to assess and further enhance the C-ITS service quality.
- Relevant indicators have been chosen by combining **telecommunication** system performance indicators with **C-ITS communication** performance indicators and excluding non-relevant metrics.

Key Performance Indicator (KPI)	Description	Unit
Availability		
Network coverage	Also, geographic coverage. Percentage of the road network and/or selection of road classes (to be case by defined) where cellular mobile network is available. (Adapted from EU EIP 2022)	%
Reliability		
Packet loss rate	Packets not received by the destination application within the maximum tolerable end-to-end latency for that application.	%
Integrity		
Latency: End to end latency	Time since a message is transmitted until it is received, at application layer	ms
Throughput (network, capacity), communication	Instantaneous data rate/throughput as perceived at the network layer	bps

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2. Service level framework for C-ITS services

- Service level framework includes the most critical KPI for C-ITS services to **operate on mobile networks**. The framework is divided into four levels of operability: **unreliable (0), basic (1), medium (2), and high (3).**
- Each selected C-ITS service is **available in real-time** manner in the Level 3. Similarly, **none or unreliable** operability of the services is at Level 0. Between Levels 1–2 each service availability may vary, i.e., the performance of the service may face delays, or the service may not be available.

Key Performance Indicator (KPI)	Level 0: Unreliable operability	Level 1: Basic operability	Level 2: Medium operability	Level 3: High operability
Availability	No or unreliable network coverage	Verified network coverage	Verified network coverage	Verified network coverage
Reliability	Reliability < 90 %, Packet loss rate > 10 %	Reliability > 90 %, Packet loss rate < 10 %	Reliability > 95 %, Packet loss rate < 5 %	Reliability > 99 %, Packet loss rate < 1 %
Integrity	End-to-end Latency > 1 s Throughput < 5 Mbps (download and upload)	End-to-end Latency < 1 s Throughput > 5 Mbps (download and upload)	End-to-end Latency < 500ms Throughput > 20 Mbps (download and upload)	End-to-end Latency < 100ms Throughput > 100 Mbps download, > 25 Mbit/s upload

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3. Scenario framework

- The scenarios aim to **simulate the total load that different C-ITS services** could cause to the mobile network. Study takes into consideration variables related to the **number of vehicles** capable of **receiving and sending C-ITS-messages**, **traffic volume**, as well as to the **information density** factors of C-ITS-messages.
- The total capacity needs of a single C-ITS service is **product of number** of vehicles receiving/sending a message, update rate of a message, information density (number of hazards, traffic control messages or traffic signals (n) in the length/area of relevance), and size of a message.

Use Case / Information density factors	RWW: Lane closure (and other restrictions)	HLN: Temporarily slippery road	SI: Signal Phase and Timing Information	PVD: Vehicle Data Collection	Collective perception
Participating vehicles per road km (High traffic roads) / km^2 (Main streets)*	**High traffic road**: 6-150	**High traffic road**: 6-150	**Main streets**: 25-127	**High traffic road:** 6-150	**Main streets**: 5-127
Update rate (or sensor update rate) (Hz)	0.1 Hz	0.1 - 1 Hz	0.5 - 4 Hz	0.1 - 1 Hz	1 - 10 Hz
Density Parameters values included in the length or area of relevance (10 km or 1 km2)	Number of traffic control messages (estimated per 10 km length of relevance) **1 - 5**	Number of hazards (estimated per 10 km length of relevance) **1 - 10**	Traffic signals (n) in the area (estimated per km^2) **5 – 19**	Vehicles participation percentage **100%, 50%, 10%**	Number of new detections per vehicle **10 - 43**
Length (km) or area (km^2) of relevance	10 km	10 km	1 km^2	10 km (10 x 1 km)	1 km^2
ETSI C-ITS message type	DENM	DENM	SPAT (4 signals)	CAM	CPM
Size of message (bytes)	400	400	1600	100	1000 -1600

**Extreme case with the busiest roads 366 veh./km.*

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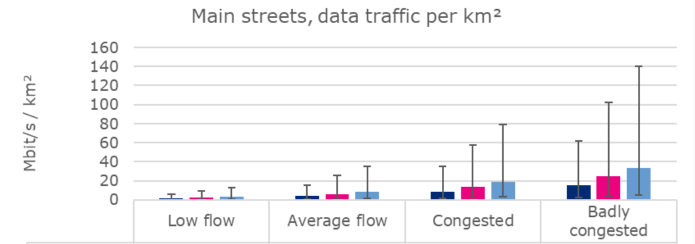
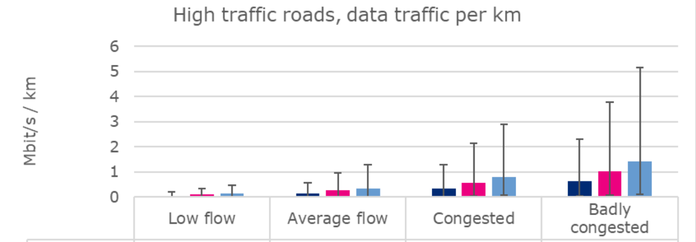
3. Scenarios for the study

- To estimate the total load that the C-ITS-services would cause to the mobile network, **two environments** were considered:
  - **main streets** (primarily in urban and suburban areas like city/municipality centrums)
  - **high-traffic roads** (high-ways connecting cities).
- In these environments all the C-ITS-services that could be active simultaneously are considered, and the total load of these services is presented in the charts.



	Low flow	Average flow	Congested	Badly congested
Pessimistic	1,4	3,7	8,4	14,9
Realistic	2,3	6,1	13,8	24,6
Optimistic	3,1	8,4	18,8	33,5

C-ITS adoption: Pessimistic Realistic Optimistic



	Low flow	Average flow	Congested	Badly congested
Pessimistic	0,06	0,2	0,4	0,6
Realistic	0,10	0,3	0,6	1,0
Optimistic	0,13	0,4	0,8	1,4

C-ITS adoption: Pessimistic Realistic Optimistic

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4. Mobile network capacity estimates

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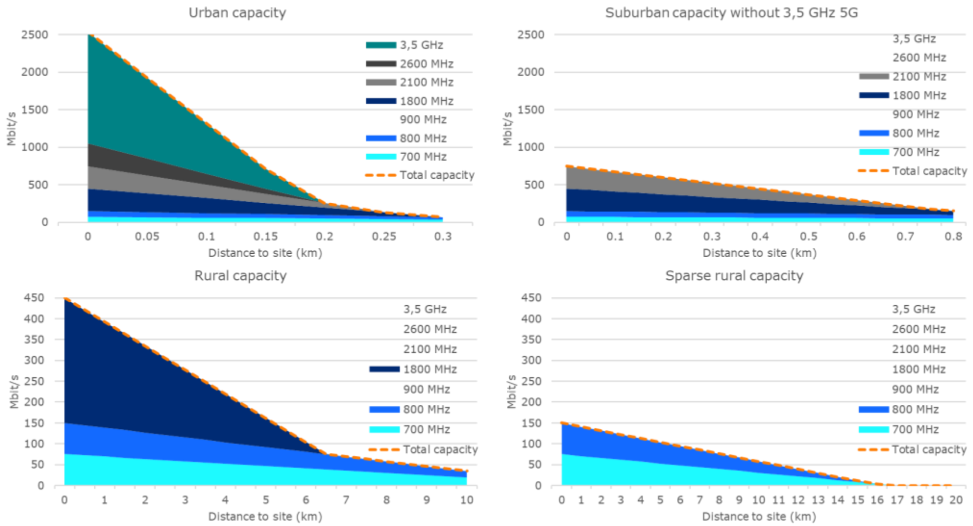
- Mobile networks utilize **different spectrum bands** to provide coverage and capacity. Higher bands offer high capacity, but over shorter distances compared to lower bands.
- In **urban and suburban areas**, extensive deployment of various spectrum bands results in high network capacity.
- In **rural areas** the higher spectrum bands cannot provide coverage to large enough areas to justify large-scale deployment, and the capacity options for operators are therefore limited.
- The capacity of the rural areas remains notably lower, while **the service areas** can be 10 to 30 times larger than suburban areas.



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4. Measurement method framework

Measurement framework

Field measurements

Coverage predictions
Identify potential problem areas for further study

Drive tests
- Scanner
- Latency test
- Stress test
  - DL throughput
  - UL throughput

Fixed point tests
Tests over longer time period to verify service availability during different times

Available information review

Traficom:
☑ collects coverage predictions from operators

Cove-rage	Basic	30 Mbit/s	100 Mbit/s	300 Mbit/s	1 000 Mbit/s
4G	☑	☑	☑	☑	
5G	☑	☑	☑	☑	☑

☑ conducts measurements to validate service availability

Additional information requirements

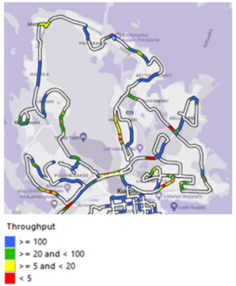
Additions:
☑ collected information sufficient
☑ analyse per operator to identify the potential problem areas

☑ include throughput measurement to assess service level availability

Test case	Current method	Proposed method
Scanner	☑ Measure frequencies of all operators	☑ Measure frequencies of all operators
Voice service	☑ Voice call success	☒ not relevant for C-ITS
Data service	☑ Ping tests ☒ no throughput measurements	☑ Ping tests ☑ Throughput measurement (stress test)
Application simulation (option)	☒ none	☐ service-level tests ☐ service-specific tests

Coverage validation

Measurement analysis



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5. Results

- The results indicate that with the assumed C-ITS message frequency and size the **mobile network capacity can serve the estimated C-ITS data traffic** levels.
- However, due to the uncertainty around the potential C-ITS messaging implementation regarding, e.g., messaging frequency, there could be **issues in serving C-ITS traffic in sparse rural areas and in rural roadside base stations** in the very worst-case scenario.
- The **worst-case scenario likelihood is rather low**, and it can be accounted for in the development of C-ITS, by planning the messaging in a way to prepare for situations of extreme congestion.

Low utilization		Medium utilization			High utilization					
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

	Main streets capacity utilisation Capacity per km² (Mbits/s/km²)			High traffic roads capacity utilisation Capacity per km (Mbit/s/km)				
Area:	**Urban**	**Suburban**	**Suburban** (no 3,5 GHz)	**Urban**	**Suburban**	**Suburban** (no 3,5 GHz)	**Rural**	**Sparse rural**
Low flow								
Pessimistic								
Realistic								
Optimistic								
High: Pessimistic								
High: Realistic								
High: Optimistic								
Average flow								
Pessimistic								
Realistic								
Optimistic								
High: Pessimistic								
High: Realistic								
High: Optimistic								
Congested								
Pessimistic								
Realistic								
Optimistic								
High: Pessimistic								
High: Realistic								
High: Optimistic								
Badly congested								
Pessimistic								
Realistic								
Optimistic								
High: Pessimistic								
High: Realistic								
High: Optimistic								
Busiest roads								
Extreme								

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Limitations of the study

- The C-ITS feasibility estimate:
  - Considers the **joint capacity of the three commercial operators**, but the service level experienced by end-user might be different to this, i.e. there might be operator specific lack of coverage that was not recognized in this study.
  - Assumes that the C-ITS data traffic is **evenly distributed** to the three commercial networks.
- There are still many uncertainties related to the **adoption rate and deployment of the C-ITS services**, which could significantly influence the volume of data transmitted over mobile networks. This is illustrated by the wide range of threshold values in C-ITS capacity demand estimates (scenarios for the study).

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Key take aways

- The commercial 4G and 5G **mobile networks of 2023 are largely able to support the expected C-ITS data traffic of 2030** (from the perspective of coverage availability and system capacity, including throughput and latency).
- Mobile networks include by nature some level of unreliability, but C-ITS services can **adapt this by intelligent service design**.
- Solutions **to deal with potential local coverage and service availability issues** are also available.

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Way forward

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Possible solutions (to ensure needed capacity)

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Network expansion	Mobile network expansion is driven by regulation and business potential and operators build capacity where users are concentrated. Issues in capacity are localized and temporary by nature, and therefore building the capacity for worst case might lead to excess capacity in many cases. Future technical solutions include 5G and Non-Terrestrial Networks (NTN).
Neutral host networks	Operational model for sharing mobile network capacity among multiple Communication Service Providers (CSP) has proven commercial viability in high-capacity demand areas. Operation model can facilitate 5G & 6G implementation (by lowering investment costs in base station infra) and improve mobile network connectivity proactively in low demand areas.
Network slicing	Network slicing ensures sufficient capacity for C-ITS services in 5G networks by allocating specific capacity to all network users during low demand and reserving critical capacity for high-demand situations. The service level framework of this study can be utilized to define suitable capacity demand.
Network monitoring	Mobile network operators monitor and improve network performance on regular basis and regulatory authorities collect coverage predictions from MNOs and implement field measurements if needed. This study didn’t recognize any clear need to collect more detailed information from the MNOs. Service-level agreements could be utilized to ensure minimum network quality for the crucial part of the road network.
C-ITS-service data communication mitigation techniques	Intelligent planning of the C-ITS services by understanding the mobile network limitations is critical to ensure the network capacity adequacy. With the larger adoption rates of C-ITS-services and multiple service providers this could also mean cooperation between different C-ITS service operators to avoid transferring duplicate information. Such cooperation models don’t yet exist but could be part of the future development such as the C-Roads Platform’s actions related to IP based Interchange Node communication.

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Large-scale adoption of C-ITS

- There are still many uncertainties related to the adoption rate and deployment of the C-ITS services.
- C-ITS services promise safety and efficiency benefits but face delays in deployment.
- Using commercial mobile networks for C-ITS reduces public investment needs, allowing resources for new sources of traffic information (data and infrastructure updates).
- C-Roads specifications should acknowledge this shift to C-V2X communication (in terms of appropriate terminal device and PKI certificate technology).
- Regulation driven approach is a very good and solid long-term plan but has rather slow deployment schedule.
- Cloud to cloud communication-based interchange network (Interchange Nodes) can be used by data and service providers to gather and stream data.
- All services and definitions doesn't need to be in place and solutions doesn’t need to solve everything in the beginning.
- Flexible solutions can utilize the available standardization but not be limited by it.

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The importance of mobile communication network

- Mobile networks are vital for C-ITS service adoption, with anticipated growth in overall connectivity demand.
- Collaborative efforts between mobile operators, road authorities, and service providers are essential for effective C-ITS support.
- Considering the entire transportation segment, including automated mobility and urban air mobility (UAM), provides a holistic view of future demand on mobile network.
- Automated mobility, especially remote operations, may require higher capacity and latency, emphasizing the importance of concepts like network slicing.
- Aerial applications, like drones, introduces uncertainties, that needs to be considered with designing of mobile networks and network expansion.

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Recommendations

Coordination group

- The central part of the cooperation model would be to tackle uncertainties related to the deployment of C-ITS services with shared view and situational awareness between actors.
- The different actors needed for the cooperation are mobile network operators, road operators and other national regulatory authorities, large fleet operators as well as C-ITS service providers.
- Themes for coordination group to promote are:
  - influencing legislation
  - defining specifications
  - building resiliency
  - assessing the impacts of C-ITS

National C-ITS implementation strategy and road map

- The strategy would aim for a certain timeline with a minimum set of C-ITS services available in the most critical parts of the road network.
- A road map would help to prioritize and scale up the operations in terms of available C-ITS services and road network coverage.
- A possible role for management and administration of C-ITS implementation could include public authority funding, e.g. road authority and municipalities, and procurement in a similar manner as it is currently the case, for example with road maintenance.
- This might be the initial step to ramp up the C-ITS services and the road map should include more detailed plan for wider emergence of commercial service providers.

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