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CJ. Bernardos
UC3M
A. Mourad
InterDigital
T. Jiang
CMCC
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Integrated Sensing and Communications (ISAC) for CATS
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Abstract

Integrated Sensing and Communications (ISAC) represents a paradigm shift in wireless networks, where sensing and communication functions are jointly designed and optimized. By leveraging the same spectral and hardware resources, ISAC enables advanced capabilities such as environment perception, object tracking, and situational awareness, while maintaining efficient and reliable data transmission. This integration holds great potential for applications in areas such as autonomous systems, smart cities, and industrial automation, where precise sensing and low-latency communication are critical. This document presents the ISAC as a typical CATS scenario to facilitate discussions on the potential challenges and requirements.

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1. Introduction

Integrated Sensing and Communications (ISAC) is emerging as a key enabler for next-generation wireless networks, integrating sensing and communication functionalities within a unified system. By leveraging the same spectral, hardware, and computational resources, ISAC enhances network efficiency while enabling new capabilities such as high-resolution environment perception, object detection, and situational awareness. This paradigm shift is particularly relevant for applications requiring both reliable connectivity and precise sensing, such as autonomous vehicles, industrial automation, and smart city deployments. Given its strategic importance, ISAC has gained significant traction in standardization efforts.

While the ETSI Industry Specification Group (ISG) on ISAC has been established to explore technical requirements and use cases, the 3GPP organization has approved the 5G study work in its release 20 (rel-20) and initiated the investigation on ISAC-related features [TR.23.700-14]. Moreover, 3GPP has agreed to continue the sensing related research on future 6G systems. Furthermore, research initiatives within the IEEE and IETF are investigating how ISAC can be integrated into network architectures, spectrum management, and protocol design, making it a critical area of development in the evolution of wireless networks.

This document presents the ISAC as a typical CATS scenario, being supplementary to the CATS use cases as in [I-D.ietf-cats-usecases-requirements], to facilitate discussions on the potential challenges, and requirements. Further, the document references the new draft on CATS reference model [IETF-CATS-RefModel-ACN] to briefly discuss how the ISAC case may leverage the model.

2. Computing Aware distributed sensing for Integrated Sensing and Communications

Integrated Sensing and Communications (ISAC) enables wireless networks to perform simultaneous data transmission and environmental sensing. In a distributed sensing scenario, multiple hardware network entities, such as base stations, access points, or edge devices (e.g., wireless terminal equipment), and intelligent agents deployed as software instances on the entities (e.g., AI-agents) -- collect raw sensing data from the environment. These data can include radio frequency (RF) reflections, Doppler shifts, channel state information (CSI), or other physical-layer features that provide insights into object movement, material composition, or environmental conditions. To extract meaningful information, the collected raw data must be aggregated and processed by a designated computing node with sufficient computational resources. This requires efficient coordination between sensing nodes and computing resources to ensure timely and accurate analysis, making it a relevant scenario for Computing-Aware Traffic Steering (CATS) in IETF.

2.1. CATS of ETSI ISAC

This use case aligns with ongoing efforts in standardization bodies such as the ETSI ISAC Industry Specification Group (ISG), particularly Work Item #5 (WI#5), titled ’Integration of Computing with ISAC’. WI#5 focuses on exploring different forms of computing integration within ISAC systems, including sensing combined with computing, communications combined with computing, and the holistic integration of ISAC with computing. The considerations outlined in this document complement ETSI’s work by examining how computing-aware networking solutions, as developed within CATS, can optimize the processing and routing of ISAC sensing data.

As an example, we can consider a network domain with multiple sites capable of hosting the ISAC computing "service", each with potentially different connectivity and computing characteristics. Figure 1 shows an exemplary scenario. Considering the connectivity and computing latencies (just as an example of metrics), the best service site is #n-1 in the example used in the Figure. Note that in the figure we still use the old terminology in which by ICR we mean Ingress CATS-Forwarder [I-D.ietf-cats-framework], and by ECR we mean Egress CATS-Forwarder.

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   (   ---------- | |   )   (  ----------       )   (  ---------- | |  )
   (   |service | |-    )    ( Serv. site #N-1 )    (  |service | |-   )
   (   |contact | |     )     -------+----------     (  |contact | |   )
   (   |instance|--    )   Computing  \              (  |instance|--   )
    (  ----------      )   delay:4ms   \              ( ----------     )
     ( Serv. site #1 )           --------+--           ( Serv. site #N )
      -------+--------      ----| ECR#N-1 |----       ---------+-----
              \  Computing --     -----------    --  Computing  /
               \ delay:10ms      Networking          delay:5ms /
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             | UE1 | /
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Figure 1: Exemplary scenario

2.2. CATS of 3GPP ISAC

3GPP has specified in the stage-1 document [TR.22.870] the requirements & objectives of ISAC service. Fundamentally, the ISAC service includes offering wide area multi-dimensional sensing that provides spatial information about non-connected objects as well as connected devices and their movements and surroundings. Successively, the 3GPP SA2 WG has approved a study item (SID) in its rel-20 and initiated the investigation on ISAC-related features [TR.23.700-14]. Moreover, 3GPP has agreed to continue the sensing related research on the on-going 6G studies.

The Figure 2 describes a possible sensing architecture that conforms to the architectural assumptions as in [TR.23.700-14]. The figure shows that there could be multiple authorized sensing entities, e.g., (R)ANs, TEs (with sensors). Also, a new sensing function, i.e., SeNF, is promoted. Note the name of the sensing function is still up for discussion.

```
   SeNF: Sensing Network Function
   Sensing Entities: TE (Terminal Equip), (g)RAN
          ...........................................
          :                                +-----+  :   +-------+
          :                                | NEF |------| AF/AS |
          :      +-----+                   +-----+  :   +-------+
          :      | AMF |                      |     :
          :      +-----+                      |     :
          :         |       +------+      +-----+   :
          :   ......|.......| SeNF |------| PCF |   :
          :   :     |       +------+      +-----+   :
          :   :     |      /                        :
+------+  :   :     |     /                         :
| TE#1 |......:     |    /                          :
+------+  :   :     |   /                           :
+------+......:  +------+        +-----+            :  +--------+
| TE#2 |--:------|(g)RAN|--------| UPF |------------:--|  Data  |
+------+  :      +------+        +-----+            :  | Network|
          :                                         :  +--------+
          :.........................................:
```

Figure 2: 3GPP ISAC exemplary scenario

There might be multiple SeNFs in a wireless network, with each SeNF capable of handling both the CP and UP of the sensing service. A SeNF can process received sensing data, aggregate sensing reports, run detection algorithms, and filter noise - to produce the sensing result that meets the service request. A SeNF may also expose the sensing results to external App servers (namely AS'es). Given the complex yet computationally-heavy tasks as conducted by the SeNF, the selection of an optimal SeNF (among all SeNF candidates) embodies the principles of CATS.

Sensing entities on (authorized) UEs may instantiate as software AI-agents with sensing functionality. If there is a large amount of collected sensing measurement data, then there might be a need to expose (i.e., transmit) the data to (external) service instances (e.g., in local premise) for optimized processing (if the local compute power at an agent is insufficient or is overloaded). After that can the processed sensing results be sent to the original sensing requestor for further processing. This kind of task redirection for better processing efficiency conforms to what the CATS strives for.

2.3. Relation to CATS

In the distributed sensing scenario, the sensed data collected by multiple nodes must be efficiently routed to a computing node capable of processing it. The choice of the computing node depends on several factors, including computational load, network congestion, and latency constraints. CATS mechanisms can optimize the selection of the processing node by dynamically steering the traffic based on computing resource availability and network conditions. Additionally, as sensing data is often time-sensitive, CATS can ensure low-latency paths while balancing computational demands across different processing entities. This capability is essential for real-time applications such as cooperative perception for autonomous systems, industrial monitoring, and smart city infrastructure.

Further, the draft [IETF-CATS-RefModel-ACN] has proposed a CATS reference model that operates on general reference points for the signaling exchanges of various types of metrics, i.e., network, compute and the new AI-agent metrics as defined in the draft. The ISAC scenario for CATS may leverage the model for better operations. For example, the IETF Draft of CATS reference model for ACN defines the reference points or RPs, e.g., the RPs between C-PS --- C-NMA, C-PS --- C-SMA, and AIA (AI-agent) --- C-PS, etc. The ISAC scenario may leverage the AI-agent logics and extend the RPs to sensing: AIA (sensing) --- C-PS. In some scenario in the context of 3GPP, here the C-PS can even be a 3rd-party entity like AF/AS.

2.4. Requirements

Several challenges need to be addressed for efficient distributed sensing in ISAC-enabled networks:

* Traffic Steering and Resource Allocation: Ensuring that sensing data is directed to the most suitable computing node while considering both network conditions and processing availability.

* Latency Sensitivity: Many ISAC applications require near-real-time processing, necessitating low-latency and high-reliability data forwarding strategies.

* Data Synchronization: Sensing nodes may have different perspectives on the environment, requiring synchronization and fusion of data streams before processing.

* Scalability: As the number of participating sensing nodes increases, mechanisms must efficiently distribute and balance the computational workload.

* Security and Privacy: Sensed data may contain sensitive information, requiring mechanisms for secure transmission and processing.

* Holistic Reference Model: Potentially a general CATS reference model with reference points for the signaling exchanges of various types of metrics among CATS entities and sensing entities.

2.5. Additional remarks

The integration of ISAC-based distributed sensing into CATS frameworks may require enhancements in computing-aware routing protocols, traffic steering algorithms, signaling mechanisms, and potentially the integration of the CATS reference model. Standardization efforts could focus on defining metrics for computing-aware path selection that is based not only on the existing CATS metrics but also with any future extensions (e.g., 'AI-agent metrics' in [IETF-CATS-RefModel-ACN]), developing mechanisms for real-time coordination between sensing and computing nodes, and ensuring interoperability with existing network architectures. Furthermore, coordination with ETSI & 3GPP may help align the development of computing-aware ISAC networking solutions with ongoing standardization efforts in computing integration, ensuring cross-industry compatibility and deployment feasibility.

3. IANA Considerations

N/A.

4. Security Considerations

TBD.

5. Acknowledgments

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Authors’ Addresses

Carlos J. Bernardos
Universidad Carlos III de Madrid
Av. Universidad, 30
28911 Leganes, Madrid
Spain
Phone: +34 91624 6236
Email: cjbc@it.uc3m.es
URI: http://www.it.uc3m.es/cjbc/

Alain Mourad
InterDigital Europe
Email: Alain.Mourad@InterDigital.com
URI: http://www.InterDigital.com/

Tianji Jiang
China Mobile
Email: tianjijiang@yahoo.com