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GROUP REPORT

Non-IP Networking (NIN);
Implementing Non-IP networking over 3GPP cellular access

Disclaimer

Reference

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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Non-IP Networking (NIN).

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Executive summary

The present document describes and recommends approaches to test Non-IP Networking (NIN) over cellular radio access. This includes existing mechanisms specified by 3GPP for both LTE and 5G Radio Access Networks, as well as guidance on enabling a non-IP protocol stack directly atop the 3GPP PHY radio layer.

Introduction

The earliest digital cellular radio network ('2G') implemented circuit switching for voice and data services, providing a dedicated circuit between sender and receiver. Whilst this can guarantee bandwidth for the circuit, it is not an efficient use of network resources where communication flows are not constant and not at full capacity.

Hence cellular networks have implemented packet switching since the release of General Packet Radio Switching (GPRS) in 2000, allowing packets to share available routing resources. There has been a steady move towards an "all-IP" architecture with the releases of 3G, 4G (LTE) and 5G. The hypothesis was that this would drive down cost - since switch and router vendors were already producing IP kit for wired networks - and that it would enable interconnection with external IP networks and devices.

The result has been that 3rd Generation Partnership Project (3GPP) specifications for cellular networks necessitate the use of IP. The phrase "all-IP" networks is a misnomer, since the TCP/IP stack is encapsulated ('tunnelled') in a bespoke 3GPP protocol stack to isolate a user's traffic from other users; secure, compress and transport data over the radio air interface; and to support mobility.

The 'Efficient use of Spectrum' clause of ETSI GR NIN 001 [i.6] explains the issues these can cause in cellular networking. Non-IP networking aims to support native mobility and multihoming, security by design, shorter headers, and in-network congestion control for improved performance to mitigate these issues. This motivates investigation into what parts of the current 3GPP protocol stack can be considered redundant, and removed, in a Non-IP networking implementation; how to test such an implementation; and how to compare performance against the TCP/IP protocol suite.

The present document describes, compares and recommends approaches to test Non-IP Networking (NIN) over a 3GPP cellular network (LTE and 5G). This includes existing mechanisms specified by 3GPP for both LTE and 5G Radio Access Networks that account for non-IP protocol types. The present document also suggests the building blocks required to test fully 'clean slate' non-IP networking atop the 3GPP PHY radio layer, and includes example scenarios and non-technical considerations across all tests. Scalability of non-IP networking to live 5G networks is also discussed.

1 Scope

1.0 Summary

The present document describes considerations for testing Non-IP Networking over 5G cellular Radio Access Networks. Although the LTE protocol stack is not explicitly considered the approach will be similar: either to use a clean-slate approach or one of the hooks provided by 3GPP to encapsulate non-IP PDUs. Fixed-line networks and Wi-Fi® are not in scope of the present document; although it may be that some of the material may be of relevance to those contexts.

The initial scope of testing is a simple proof of concept: to demonstrate communication between two remote processes over a radio air interface using Non-IP network protocols. This involves at minimum the UE, the air interface, the 3GPP gNb or eNb, and a data plane that communicates using Non-IP Networking. Depending on the test approach chosen (as described in clauses 6 and 7), certain elements of the 3GPP architecture may be utilized or adapted. If successful then this proof of concept should be extended to comparative testing against IP networking per the KPIs published in ETSI GS NGP 012 [i.7].

1.1 Access technologies

The present document covers testing over 3GPP 5G radio access networks, with LTE possible for the 'clean slate' approaches document in clauses 7 and 8.

1.2 Out of Scope

The present document does not cover interoperability with IP-based networks, including roaming scenarios between 3GPP mobile network operators. These may be covered in future documents following a successful test of the simple proof-of-concept.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] 3GPP System architecture milestone of 5G Phase 1 is achieved.

NOTE: Available at https://www.3gpp.org/NEWS-EVENTS/3GPP-NEWS/1930-SYS_ARCHITECTURE.

[i.2] eCPRI Specification V2.0: "Common Public Radio Interface: eCPRI Interface Specification".

NOTE: Available at http://www.cpri.info/downloads/eCPRI_v_2.0_2019_05_10c.pdf.

[i.3] eCPRI: "Specification Overview".

NOTE: Available at http://www.cpri.info/spec.html.

[i.4] IEEE P802.CMTM™: "Time-Sensitive Networking for Fronthaul".

NOTE: Available at https://1.ieee802.org/tsn/802-1cm/.

[i.5] IETF draft-charter-ietf-6lowpan-06: "IPv6 over Low power WPAN (6lowpan)".

NOTE: Available at https://datatracker.ietf.org/wg/6lowpan/about/.

[i.6] ETSI GR NIN 001: "Non-IP Networking (NIN); Problem Statement: networking with TCP/IP in the 2020s".

[i.7] ETSI GS NGP 012: "KPIs for Next Generation Protocols: Basis for measuring benefits of NGP".

[i.8] ETSI TS 138 425: "5G; NG-RAN NR user plane protocol (3GPP TS 38.425)".

[i.9] ETSI TS 123 502: "5G; Procedures for the 5G system (5GS) (3GPP TS 23.502)".

[i.10] ETSI TS 123 682: "Digital cellular telecommunications system (Phase 2+) (GSM); Universal Mobile Telecommunications System (UMTS); LTE; Architecture enhancements to facilitate communications with packet data networks and applications (3GPP TS 23.682)".

[i.11] ETSI TS 122 261: "5G; Service requirements for the 5G system (3GPP TS 22.261)".

[i.12] ETSI TS 124 502: "5G; Access to the 3GPP 5G Core Network (5GCN) via non-3GPP access networks (3GPP TS 24.502)".

[i.13] "ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 KHz to 300 GHz)", International Commission on Non-Ionizing Radiation Protection, 2020.

NOTE: Available at https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf.

[i.14] GSMA, June 2019: "NB-IoT Deployment Guide to Basic Feature set Requirements".

NOTE: Available at https://www.gsma.com/iot/wp-content/uploads/2019/07/201906-GSMA-NB-IoT-Deployment-Guide-v3.pdf.

[i.15] ETSI TS 123 401: "LTE; General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access (3GPP TS 23.401)".

[i.16] FreeRTOS: "Adding the TCP/IP Source Files to an RTOS Project".

NOTE: Available at https://freertos.org/FreeRTOS-Plus/FreeRTOS_Plus_TCP/TCP_Networking_Tutorial_Adding_Source_Files.html.

[i.17] Office of Communication (Ofcom): Radiocommunications licence.

NOTE: Available at https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences.

[i.18] CPRI: "Common Public Radio Interface", diagram of eCPRI protocol stack over IP/Ethernet.

NOTE: Available at http://www.cpri.info/downloads/eCPRI_Presentation_for_CPRI_Server_2018_01_03.pdf.

[i.19] ETSI TS 123 501: "5G; System architecture for the 5G System (5GS) (3GPP TS 23.501)".

[i.20] ETSI TS 138 300: "5G; NR; NR and NG-RAN Overall description; Stage-2 (3GPP TS 38.300)".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

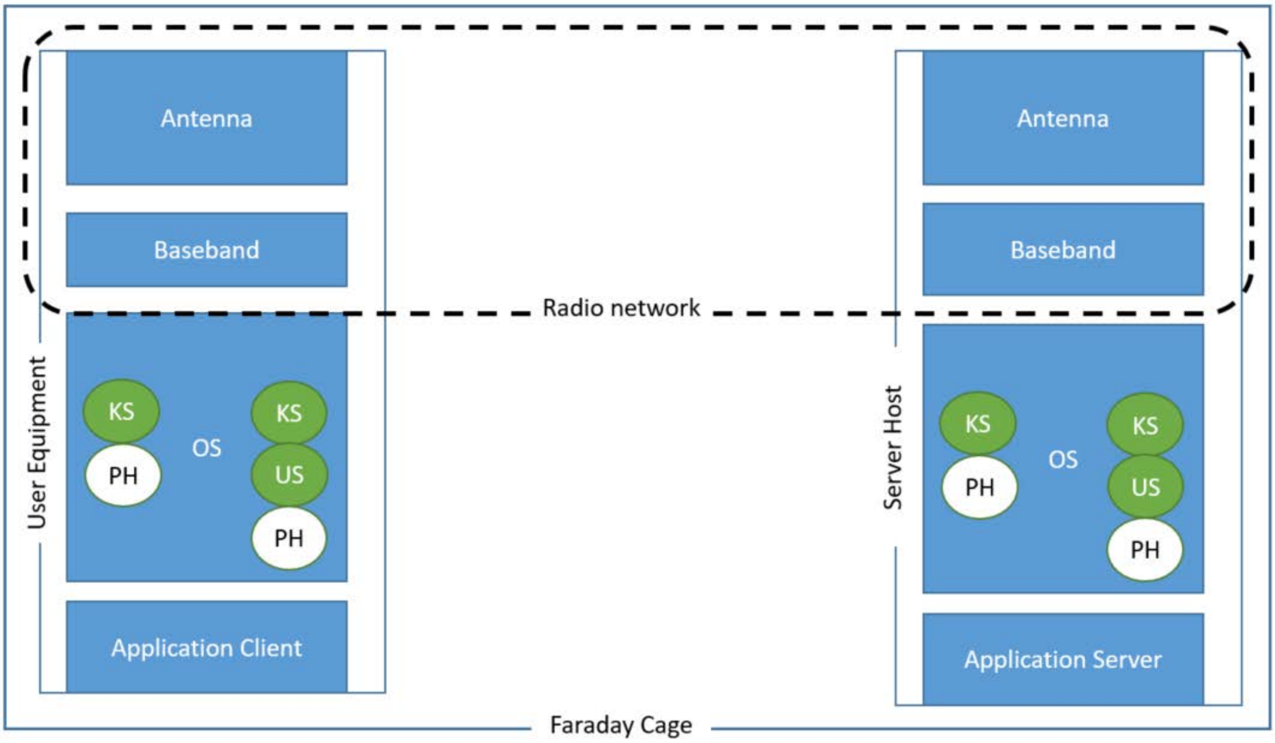
3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

5GCN	5G Core Network
BLE	Bluetooth Low Energy
CPRI	Common Public Radio Interface
DN	Data Network
EMF	Electro Magnetic Field Limits (Human Exposure)
FPGA	Field Programmable Gate Array
GPRS	General Packet Radio Service
GTP	GPRS Tunnel Protocol
ICNIRP	International Commission for Non-Ionizing Radiation Protection
IoT	Internet of Things
IP	Internet Protocol
KS	Kernel Space
L2CAP	Logical Link Control and Adaptation Protocol
LAN	Local Area Network
MAC	Media Access Control
MTU	Maximum Throughput Unit
NAS	Non-Access Stratum
NGP	Next Generation Protocols
NIDD	Non-IP Data Delivery
NIN	Non-IP Networking
NR	5G New Radio
OS	Operating System
PCI-E	Peripheral Component Interface Express
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PH	Protocol Handler library
PHY	PHYsical layer
PtP	Point-to-Point
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RLC	Radio Link Control
RRC	Radio Resource Control
RTOS	Real Time Operating System
SBA	Service Based Architecture
SCEF	Service Capabilities Exposure Function
SDAP	Service Data Adaptation Protocol
SIM	Subscriber Identity Module
TCP	Transmission Control Protocol
TNGF	Trusted Non-3GPP Gateway Function
TSN	Time Sensitive Networking
UDP	User Datagram Protocol
UE	User Equipment
UPF	User Plane Function

US	User Space
VLAN	Virtual Local Area Network
VPN	Virtual Private Network

4 Model for non-IP prototyping over radio



Legend:
KS = Kernel Space
US = User Space
PH = Protocol Handler library

Figure 4.1: Model for Non-IP prototyping over radio

The Protocol Handler may be implemented within kernel space or user space. The former requires kernel development, but can offer more control over networking operations. The user space option is easier to develop but requests networking resources from the kernel, and will hence reuse the existing TCP/IP network stack.

5 5G architecture summary

5.1 5G radio access user plane protocols

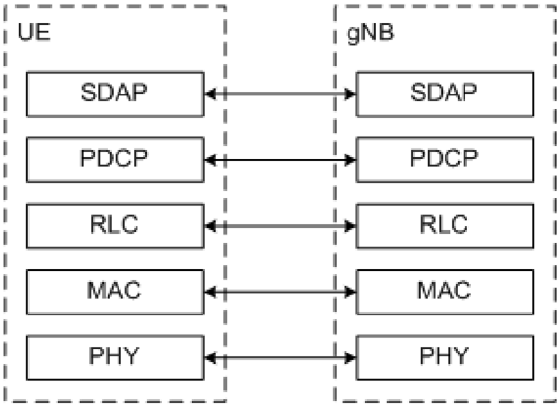


Figure 5.1: 5G radio protocol stack

The 5G New Radio (NR) user plane protocol stack [i.8] is responsible for transferring user plane data between a Radio Access Network (RAN) and User Equipment. Figure 5-1 shows the following protocols:

- the physical radio (PHY) where digital data is encoded as an analogue signal;
- Media Access Control (MAC) that handles transmissions and retransmissions;
- Radio Link Control (RLC), responsible for correcting MAC-layer errors to ensure in-order delivery of packets to the higher layers;
- The Packet Data Convergence Protocol (PDCP), which carries the IP stack user-plane traffic, supporting in-order packet delivery and queue handover during mobility between two cells, encrypting the payload and optionally compressing IP headers;
- the Service Data Adaptation Protocol (SDAP) manages uplink and downlink Quality of Service (QoS) markings for flows.

5.2 5G Service Based Architecture (SBA)

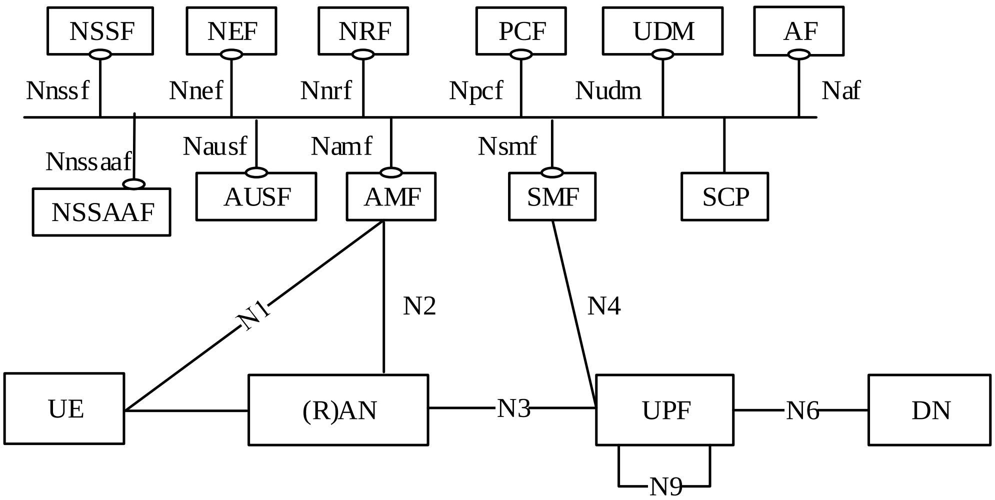


Figure 5.2: 5G Service Based Architecture (source: ETSI TS 123 501 [i.19])

The 3GPP 5G system architecture is 'service based': network functions expose interfaces to each other via a common framework [i.1]. Of particular interest to the present document is the User Plane Function (UPF) which connects to a DN (data network) via the 'N6' interface, and which provides means to encapsulate non-IP PDUs as described in clauses 6.1 and 6.2 below.

6 Testing Non-IP Networking within 5G SBA

6.1 Unstructured PDU in PDCP with no encapsulation

5G specifies support for different PDU session types [i.9], extending the non-IP data delivery feature introduced in LTE to optimize narrowband IoT transmission to low-power devices [i.10]. The 'unstructured' PDU type essentially means 'neither IP nor Ethernet PDU', since those have dedicated types. All PDU types are encapsulated within the PDCP.

This 'unstructured PDU' technique involves tunnelling from the User Plane Function (UPF) to a Data Network (DN) such as the Internet or a LAN. [i.9] states "Different Point-to-Point (PtP) tunnelling techniques may be used to deliver Unstructured PDU Session type data to the destination (e.g. application server) in the Data Network via N6. Point-to-Point tunnelling based on UDP/IP encapsulation as described below may be used. Other techniques may be supported".

Removing UDP/IP encapsulation reduces header overheads between the UPF and the RAN, but will still rely on the 5G of MAC, RLC, PDCP and SDAP layers for transmission. There is a constraint of maximum one 5G QoS Flow per PDU Session of Type Unstructured.

6.2 Unstructured PDU in PDCP with UDP/IP encapsulation

This is similar to (b) above but with the overhead of UDP/IP encapsulation to tunnel between the UPF and DN.

6.3 Non-IP within a network slice

The 5G architecture supports 'network slicing', where each slice is an isolated logical network configured atop the shared physical network infrastructure [i.11]. The intention is to allow different applications to network over slices configured to their quality demands - such as latency, loss, jitter and bandwidth - and for slices to be allocated resources by a central controller accordingly.

Network slicing could potentially transport non-IP protocols, however they would be encapsulated per clauses 6.1 and 6.2 which would remove some benefits (header size and performance)

6.4 Non-IP within a VPN

Virtual Private Networks (VPNs) can be used to tunnel a non IP protocol between a client and server, Whilst VPNs are a proven technology, with numerous VPN proxy applications available for users to install, they are not well-suited for testing non-IP networking because:

- They involve an encrypted IP tunnel, adding to header size and encryption/decryption cycles.
- They require the client device to have an IP address, precluding native testing of non-IP addressing.

6.5 Connecting the non-IP access network to the 5G core

6.5.1 ETSI TS 124 502: Access to the 3GPP 5G Core Network (5GCN) via Non-3GPP Access Networks (N3AN)

6.5.1.0 Introduction

ETSI TS 124 502 [i.12] was designed to support access to the 5G Core Network (5GCN) by Wi-Fi and fixed networks. It assumes that the non-3GPP access network is IP-based. This clause assesses whether it can be used to allow non-IP access networks to connect to the 5GCN, and if not, what changes would be required to do so.

ETSI TS 124 502 [i.12] states that the 5GCN "supports the connectivity of the UE via non-3GPP access networks. These non-3GPP access networks can be trusted non-3GPP access networks, untrusted non-3GPP access networks or wireline access networks." A non-IP radio access network would be considered a trusted or untrusted non-3GPP access network.

6.5.1.1 Trusted and Untrusted non-3GPP access

ETSI TS 124 502 [i.12] does not indicate how a state of 'trust' is achieved between a 5GCN and a non-3GPP access network - however it does indicate the different connection mechanisms to either a trusted or untrusted non-3GPP access network.

Per clause 4.5 of ETSI TS 124 502 [i.12], 'Trusted access' means that the communication between the UE and 5GCN "is secure". The UE establishes a secure IPsec connection to the 5GCN's Trusted Non-3GPP Gateway Function (TNGF), which brokers control plane and user plane procedures between the UE and the relevant parts of the 5GCN.

Per clause 4.2 of ETSI TS 124 502 [i.12], 'Untrusted access' means that the communication between the UE and 5GCN is not considered to be secure. The UE establishes a secure IPsec connection to the 5GCN's Trusted Non-3GPP Gateway Function (TNGF), which brokers control plane and user plane procedures between the UE and the relevant parts of the 5GCN. Both Trusted and Untrusted non-3GPP access therefore requires IPsec encapsulation between the UE and 5GCN. Both modes of IPsec (transport mode and tunnel mode) require an IP payload, hence, non-IP network protocols would need to be encapsulated within IP. Whilst this provides access to the 5GCN, it incurs a performance cost (additional headers to add/remove and transmit over the air interface) and reduces the performance benefit of non-IP networking.

7 'Clean slate' testing atop 3GPP PHY

7.1 Overview

A 'clean slate' approach to testing would utilize 3GPP PHY (the Physical Radio Layer). This, along with radio hardware, would encode digital data to an analogue signal; modulate/demodulate the signal; select power, frequency, phase and time interval for transmission; and transmit and receive signals.

7.2 Radio functions

The non-IP Radio Access Networking stack would be expected to take on the functions of the existing 3GGP protocols between physical radio and IP:

- transmissions and retransmissions (done today by 3GPP Media Access Control);
- in-order delivery of packets (3GPP Radio Link Control and Packet Data Convergence Protocols);
- payload encryption (3GPP PDCP);
- connection establishment and release functions, (3GPP Radio Resource Control (RRC));

- broadcast of system information (3GPP RRC);
- radio bearer establishment, reconfiguration and release (3GPP RRC);
- mobility procedures (3GPP RRC);
- paging notification and release (3GPP RRC);
- outer loop power control (3GPP RRC);
- queue handover during mobility (3GPP PDCP);
- uplink and downlink Quality of Service (QoS) markings for flows (Service Data Adaptation Protocol);
- scheduling of radio resources:
    - amongst users, based on:
        - each user's received signal strength;
        - each user's packet queue;
    - amongst packets in a user's queue, based on:
        - any QoS markings on the packets.

Not required for non-IP networking:

- compressing IP headers (3GPP PDCP).

Once the radio layers have transmitted and received the payload, it is interpreted by a baseband Real Time Operating System (RTOS) before being passed to the Operating System (OS) network controller and onwards to the application. Both RTOS and OS today have handlers for IP, TCP and UDP. Equivalent handlers will need to be programmed for non-IP protocols in order to test them natively without any reliance on the [TCP|UDP]/IP stack.

8 Testing atop 5G PDCP

8.1 Rationale

The 'Clean slate' approach documented in clause 7 supports testing a non-IP radio network protocol stack in isolation, but requires the developer to provide all the radio functions listed in clause 7.2. Since this is not trivial, and risks and inferior implementation to well-tuned and utilized RAN deployments, a compromise approach is to identify the first layer of the 5G RAN in which IP is carried as the payload of a Protocol Data Unit (PDU) and swap-out IP with a non-IP protocol at that point.

8.2 Packet Data Convergence Protocol

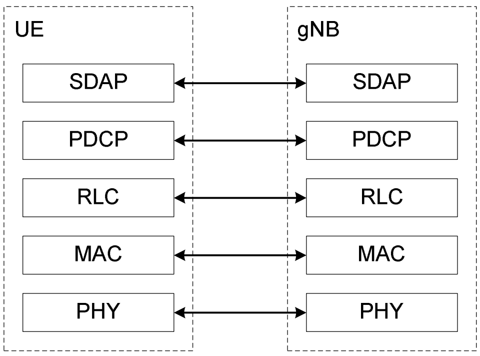


Figure 8.1: 5G RAN protocol stack (source: ETSI TS 138 300 [i.20])

Figure 8.1 shows the 5G RAN protocol stack up to and including PDCP, where IP packets are carried as the PDU payload. Hence it is PDCP that requires adaptation to instead carry a non-IP protocol stack within its PDUs.

As per clause 7.2, the PDCP will handle queue handover during mobility, payload encryption, and in-order delivery of packets. It is not required to provide IP header compression since there will be no IP payload. All other functions listed in clause 7.2 will persist as the existing 5G PHY, MAC, RLC and RRC will be reused.

9 Radio network components

9.0 Overview

This clause provides suggestions for hardware and software when prototyping non-IP networks over radio.

The radio network consists of at least two transceivers. For a given communication, one will act as the transmitter and one as the receiver. For mobility testing, two transmitters are required in addition to the receiver.

The radio network needs to support 'uplink' communications (simulating a mobile device uploading packets to the mobile network) and 'downlink' (simulating a mobile device downloading/streaming packets from the radio network).

The suggested solutions are intended to support prototyping on a low-budget, and favours modular, open-source equipment where possible.

9.1 Hardware for testing within 5G SBA

9.1.0 Overview

For testing with 5G SBA (clause 6), a basic solution can use hardwired LTE or 5G modules, e.g.:

- A single-board computer, e.g. Raspberry Pi®, with peripherals to support command input (either direct or via a remote terminal) and a free Mini PCI-E slot.
- A Mini PCI-E base shield, which allows mounting of a radio module.
- A 5G or LTE PCI-E module.
- An antenna.

Note that this setup may be used as a radio access point for other non-IP hardware which lacks its own dedicated non-IP radio interface. For example, a Non-IP system could interface with the Raspberry Pi® board over Ethernet, passing Non-IP packets encapsulated in Ethernet frames. The board would then be responsible for passing the contents of the Internet frame to the radio system for transmission within the PHY layer.

9.1.1 Software and firmware

9.1.1.1 Operating system

The operating system should include handlers for the Non-IP protocol. Depending on the requirements of the Non-IP protocol, it may or may not require implementation in kernel space or user space. Kernel space offers more control of protected system functions and primitives, but access to kernel space is restricted for security reasons in certain operating systems. User space has no such restriction but requests resources from the kernel.

An open source operating system, such as GNU/Linux, facilitates development of both kernel space and user space protocol handlers.

9.1.1.2 Baseband (Real-Time Operating System)

The baseband processor runs a Real-Time Operating System (RTOS) to manage radio control functions (frequency, modulation/demodulation, encoding/decoding). It interfaces with the Operating System on one side, and the radio antenna on the other.

A free and open source baseband, e.g. OsmocomBB, allows development of handlers between the PHY layer and networking layer above.

9.2 Radio network for 'clean slate' testing atop PHY or PDCP

9.2.1 Hardware

Requirements for radio hardware:

- two programmable transceivers (more than two for mobility testing);
- full duplex communication on uplink and downlink;
- minimum bandwidth support of 20 MHz. This should allow approximately 75 Mbps throughput depending on Modulation and Coding Scheme;
- non-technical requirements per clause 10.

9.2.2 Software and firmware

9.2.2.0 Overview

The software stack should implement the radio functions outlined in clause 7.2. An open source software stack such as Open Air Interface (https://www.openairinterface.org/) allows for deconstruction and replacement of the existing 3GPP 5G and LTE RAN layers, either in full or where IP is embedded (per clause 8).

9.2.2.1 Operating system

The radio network accepts packets from an application for downlink transmission to the receiver, and forwards packets received on the uplink to that application. This will require:

- operating system: development of kernel handlers for the non-IP networking protocols; or
- operating system: development of user space protocol handlers that request network resources from the kernel;
- sockets/ports; or
- protocol handling via FPGA.

9.2.2.2 Baseband/Real-time Operating System

Requirements for baseband/RTOS:

- Creation of handlers for the non-IP networking protocols, analogous to the TCP/IP and UDPhandlers referenced at [i.16].

9.3 Application server

The prototype assumes a client-server architecture. The server in this architecture will serve and accept the Non-IP protocol under test, which requires the Operating System handlers outlined in clause 9.2.2.1, which in turn depend on the baseband handlers in clause 9.1.1.2 to be implemented.

9.4 Application client

The client will request and present the Non-IP networking events, either via a Graphical User Interface or command line. It will require the Operating System handlers (and in turn the baseband handlers) detailed in clause 9.1.1 to be implemented.

10 Non-technical considerations

10.1 Safety

Refer to the latest international EMF guidelines [i.13].

10.2 Test environment

Requirements for test environment:

- The radio network should be within a Faraday cage to prevent interference from and to other radio networks.
- Power levels should be respected as per guidance in clause10.1.
- To test performance under signal degradation, it should be possible to attenuate the power to the network transceiver. Interference may be introduced to the signal if supported by the lab.
- To test performance under network congestion, the lab may generate additional dummy load at the scheduler.
- To test performance under mobility, two network transceivers are required.

At least one client device configured as per clause 9.2.1 is required.

10.3 Licencing

Radio licencing is country-specific, please contact your local regulator. For example, Ofcom in the United Kingdom [i.17].

10.4 Regulatory compliance

Testers should refer to their local telecommunications regulator for guidance on topics including lawful intercept, content standards, retention of records for a non-IP networking trial.

11 Comparison of the protyping approaches

Table 11.1: Comparison of approaches

Complexity / Approach	Reuse of existing 3GPP RAN	OS development	Hardware development	Baseband development	Extent to which non-IP benefits are enabled
5G with VPN	Full	No	No	No	Minimal: basic proof of networking only
5G with UDP/IP encapsulation	Full	No	No	No	Minimal: basic proof of networking only
5G with new encapsulation	Near full	No	No	No	Near full (but less than PDCP approach)
Atop 5G PDCP	Near full	Yes	Yes	Yes	Near full
Atop 5G PHY	Only PHY	Yes	Yes	Yes	Fully

In summary, more reuse of the existing 5G RAN makes testing easier, but at the cost of not realizing the full benefits of non-IP networking (since it still relies on the IP stack to some extent in those approaches). A pure 'clean slate' approach has potential to deliver the full benefits of non-IP networking but requires re-development of the entire 3GPP RAN. This is a significant amount of work, and would require stress and penetration testing at each 'layer' before a commercial deployment.

'Testing atop PDCP' (clause 8) and 'Unstructured PDU in PDCP with no encapsulation' (clause 6.2) offer a compromise, reusing the lower radio layers of the 5G RAN and swapping-out the IP stack at the earliest opportunity.

'Testing non-IP over VPN' (clause 4) does not prove any benefits of non-IP networking due to the IP encapsulation, but can be used to demonstrate basic client/server communication before moving to another approach.

12 Scaling the prototype

12.0 Overview

This clause describes how to approach testing a prototype . Since the prototyping guidelines in the present document utilize an existing PHY interface that transports LTE/5G, it is assumed that any operator subsequently testing on their macro radio network is compliant with local regulations (such as use of licenced spectrum, power emissions, RADAR avoidance, etc.).

12.1 Fronthaul

A radio access network's base station includes a baseband controller (responsible for the translation to and from RF signals to digital information) and a radio head (that transceivers RF signals via the antenna).

Previous generation of radio access networks had the base station's baseband controller and radio head sited close to each other, with RF signals carried between the two by coaxial cable. This cable only delivered low-bandwidth signals, and since it was susceptible to noise and loss, restricted the height of the radio head up the mast, meaning the optimal height for best coverage was not attained.

Since LTE, 3GPP RAN supports the separation of the baseband controller and the radio head (the radio transceiver unit) over longer distances. Modern base stations have replaced the coaxial connection with fibre, which carries a digital representation of the RF signal between centralized baseband controllers and remote radio heads is known as 'fronthaul'. This digital connection may span several kilometres but has higher bandwidth and reduced loss compared to RF over coaxial, and allows improved co-ordination between adjacent cells to avoid interference. This in turn allows for a denser network with more small cells operating simultaneously.

As well as transporting digitized control plane and user plane signals, fronthaul carries synchronization information between the baseband controller and radio head.

12.1.1 Enhanced Common Public Radio Interface

The latest fronthaul standard is the Enhanced Common Public Radio Interface [i.3]. The diagram at [i.18] shows how the eCPRI protocol encapsulates control plane/user plane data, and how eCPRI itself is either:

1) optionally encapsulated in UDP/IP for transport over Ethernet; or

2) transported directly within Ethernet frames. The 'user data' and 'real-time control' payloads are digitized representations of RF signals for user plane and control plane, which in turn will carry network protocols and their payloads.

The boxes 'C&M' (control and management), 'Connection OAM' (network connection maintenance), and Synchronization, are for configuration signalling between the baseband controller and radio equipment.

12.1.2 Implication for non-IP networking

The following sections of [i.3] are of relevance for implementers of non-IP networking utilizing an eCPRI fronthaul:

- Section 3.2.1 of [i.3] specifies eCPRI directly over Ethernet frames (with no additional UDP/IP encapsulation).
- Section 3.3 of [i.3] notes that the 'Control and management' does not specify an information flow and does not preclude the use of non-IP protocols.
- Section 3.4 of [i.3] indicates that specification of Synchronization information flows is out of scope.
- QoS for eCPRI may be set using the Priority field in the VLAN tag of Ethernet frames, per section 3.5 of [i.3].

In addition, the IEEE's Time-Sensitive Networking (TSN) Task Group includes TSN for fronthaul [i.4] to control traffic scheduling, and timing synchronization over compliant Ethernet.

Although encapsulating eCPRI over Ethernet is a 'more pure' non-IP networking approach, implementers of non-IP networking in macro networks may wish to consider any existing UDP/IP fronthaul deployment, since fronthaul one-way latency is typically 100 µs and likely to be of negligible effect to performance.

13 Test scenarios

13.0 Overview

This clause suggests test scenarios appropriate to proof-of-concept testing.

13.1 Low-power IoT devices

13.1.0 Rationale for scenario

Low-power IoT devices typically suffer from significant battery drain when transceiving radio communications. Any reduction in the bytes being sent and processed will increase battery life, which is important for installations where batteries may be expected to last for years.

The Raspberry Pi® setup described in clause 9.1 can offer a suitable host for a Low Power IoT service, or a connection to a basic microcontroller that can act as the Low Power IoT client. Although the present document only covers options for 3GPP RAN communication, the tester may wish to utilize other radio protocols such as BLE (Bluetooth® Low Energy), with the non-IP payload encapsulated in the Logical Link Control and Adaptation Protocol (L2CAP).

13.1.1 Comparative testing

- A comparative low-power IoT test may be performed against a 6lowpan [i.5] implementation. Since 6lowpan utilizes 128-bit IPv6 addresses, and imposes a minimum MTU 1 280 octets, there is an opportunity to increase goodput (application bits per Hz per second) via protocols with significantly reduced header sizes and radio transmission burden, and negate the need for potentially expensive and energy-consuming header compression. The Non-IP protocol may also provide less compute-intensive security mechanisms and connection setup round-trips.
- 3GPP's Cellular IoT optimizations [i.15] (clause 4.10) were introduced to optimize data transmission for low-power IoT devices. This involves utilizing control plane signalling to convey short messages, and/or reduction of signalling round-trips involved to set-up a user plane connection.

This includes 3GPP Non-IP Data Delivery [i.15] (clause 4.3.17.8), which supports connection to IOT devices by provisioning a Non-IP access point in the network for a given device SIM. This avoids IP address allocation to that device and hence no IP headers. Routing is either via the processes in clauses 6.1 (unstructured PDU) or 6.2 (UDP/IP encapsulation) of the present document, or use of a Service Capability Exposure Function (SCEF) [i.10] (clause 4.4.8) if exposed by the network operator. The SCEF approach avoids GTP tunnelling by using DIAMETER signalling [i.15] (clause 4.3.17.8.3.2) and [i.10] (clause 5.13), i.e. the messages are sent within NAS (Non-Access Stratum) signalling messages rather than over the conventional IP-based user plane.

NOTE: The SCEF process requires an additional process for the IOT application server to register with the SCEF to be granted access for Non-IP Data Delivery.

13.2 Video and audio services

Unidirectional audio and video content, including "live" content such as sporting events, can be successfully "streamed" over current networks by transferring a succession of small files that are stored locally for a few seconds and then played out in succession. The time for which they are stored needs to be long enough to absorb variations in the time required for the transfer, including retransmission of packets that are lost due to overflow of buffers within the network.

For transmissions that are part of a conversation, such as a phone call or video conference, the round trip time is important; for a natural conversation it should be possible to interrupt the other speaker, but that is difficult if by the time the listener hears them stopping to take a breath (typically for 200 ms) they have already started speaking again. Keeping the delays low increases the chance that a packet will not arrive in time for its content to be played out, so there are drop-outs and distortions.

New applications will require even lower delays. Where the sound from a performer's microphone is sent to a mixing desk and then back to their headphones, the delay affects the performance if it is more than about 25 ms; a similar figure applies when musicians in different locations are performing together. In the case of sound reinforcement in a performance space, the loudspeakers will need to be about 330 mm nearer to the audience for every millisecond of delay. The transition from analogue transmission (which has no buffering delays) to digital networks will see an increasing demand for truly low-latency services.

Tests should compare an implementation using current 3GPP standards against one using the Flexilink guaranteed service, with flows connected across a core network on which the load is increased by adding simulated competing traffic. Objective latency measurements can be performed using a pulse generator and an oscilloscope. There should also be subjective tests with live musicians. Results of each kind of test would be suitable subjects for academic papers.

Similar tests can be done with video, for instance so that remote performers can see as well as hear each other, although at the low frame rates common in videoconferencing (typically too low for lip-reading) visual cues are in any case less accurate.

13.3 Tactile

One application that has been proposed for 5G is remote surgery, which is robotic surgery where the surgeon and the robot are not in the same room. Wireless transmission is preferred, to remove the requirement to sterilize cables between operations.

The surgeon needs to be able to feel what the robot is doing, and round trip time requirements can be as low as one millisecond. This also applies to other kinds of remote manipulation.

As with audio, objective measurements would provide definitive latency figures but there should also be subjective tests of the application.

History

Document history		
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