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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Information-centric networking – Overview, standardization gaps and proof-of-concept

ITU-T Y-series Recommendations – Supplement 47

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Supplement 47 to ITU-T Y-series Recommendations

Information-centric networking – Overview, standardization gaps and proof-of-concept

Summary

Supplement 47 to ITU-T Y-series Recommendations provides the overview of information-centric networking (ICN) and describes the fifteen standardization gaps and five proof-of-concept technologies investigated by the ITU-T Focus Group on IMT-2020 (FG IMT-2020) during 2015-2016. It is based on the ICN related contents of the two final output documents of FG IMT-2020 [b-FG IMT-2020 Gaps] and [b-FG IMT-2020 ICN PoC].

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Information-centric networking – Overview, standardization gaps and proof-of-concept

1 Scope

This Supplement describes fifteen standardization gaps and five proof-of-concept technologies investigated by the ITU-T Focus Group on IMT-2020 during 2015-2016.

2 References

None.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 IMT-2020 [b-ITU-T Y.3100]: systems, system components, and related technologies that provide far more enhanced capabilities than those described in [b-ITU-R M.1645].

NOTE – [b-ITU-R M.1645] defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000 for the radio access network.

3.1.2 latency [b-ITU-R M.2083-0]: the contribution by the network to the difference in time (in ms) between when the source sends a packet and when the destination receives it.

3.1.3 mobility [b-ITU-R M.2083-0]: from a performance target point of view, mobility is the maximum speed (in km/h) at which a defined QoS and seamless transfer can be achieved between radio nodes, which may belong to different layers and/or radio access technologies (multi-layer/-RAT).

3.1.4 future network (FN) [b-ITU-T Y.3001]: A network able to provide services, capabilities, and facilities difficult to provide using existing network technologies. A future network is either:

a) A new component network or an enhanced version of an existing one, or,

b) A heterogeneous collection of new component networks or of new and existing component networks that is operated as a single network.

NOTE – The plural form "Future Networks" (FNs) is used to show that there may be more than one network that fits the definition of a future network.

3.1.5 network virtualization [b-ITU-T Y.3011]: A technology that enables the creation of logically isolated network partitions over shared physical networks so that heterogeneous collection of multiple virtual networks can simultaneously coexist over the shared networks. This includes the aggregation of multiple resources in a provider and appearing as a single resource.

3.1.6 software-defined networking [b-ITU-T Y.3300]: A set of techniques that enables to directly program, orchestrate, control and manage network resources, which facilitates the design, delivery and operation of network services in a dynamic and scalable manner.

3.1.7 identifier [b-ITU-T Y.2091]: An identifier is a series of digits, characters and symbols or any other form of data used to identify subscriber(s), user(s), network element(s), function(s), network entity(ies) providing services/applications, or other entities (e.g., physical or logical objects). Identifiers can be used for registration or authorization. They can be either public to all networks, shared between a limited number of networks or private to a specific network (private IDs are normally not disclosed to third parties).

3.1.8 locator (LOC) [b-ITU-T Y.2015]: A locator is the network layer topological name for an interface or a set of interfaces. LOCs are carried in the IP address fields as packets that traverse the network.

NOTE – In [b-ITU-T Y.2015], locators are also referred to as location IDs.

3.1.9 node ID [b-ITU-T Y.2015]: A node ID is an identifier used at the transport and higher layers to identify the node as well as the endpoint of a communication session. A node ID is independent of the node location as well as the network to which the node is attached so that the node ID is not required to change even when the node changes its network connectivity by physically moving or simply activating another interface. The node IDs should be used at the transport and higher layers for replacing the conventional use of IP addresses at these layers. A node may have more than one node ID in use.

NOTE – [b-ITU-T Y.2015] specifies a node ID structure.

3.1.10 name [b-ITU-T Y.2091]: A name is the identifier of an entity (e.g., subscriber, network element) that may be resolved/translated into address.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

5G	Fifth generation mobile network
AAA	Authentication, Authorization, Accounting
APN	Access Point Name
BGP	Border Gateway Protocol
BH	Backhaul
BRAS	Broadband Remote Access Server
CCN	Content-Centric Networking
CDN	Content Delivery Network
CN	Core Network
COTS	Commercial Off-The-Shelf
C-RAN	Cloud Radio Access Network
CS	Content Store
D2D	Device-to-Device
D2N	Device-to-Network
DASH	Dynamic Adaptive Stream over HTTP
DDD	Directional Division Duplex
DNS	Domain Name System
DRM	Digital Rights Management
E2E	End-to-End
EMS	Element Management System
eNodeB	Evolved Node B

EPC	Evolved Packet Core
FDD	Frequency Division Duplex
FIB	Forwarding Information Base
FID	Forwarding Identifier
FQDN	Fully Qualified Domain Name
GTP	Generic Tunnelling Protocol
GTP-C	GTP Control
GW	Gateway
HTTP	Hyper Text Transfer Protocol
ICN	Information Centric Networking
ICNRG	Information Centric Networking Research Group
IDC	Internet Data Centre
IMEI	International Mobile Equipment Identity
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
KPI	Key Performance Index
LAN	Local Area Network
LINP	Logically Isolated Network Partitions
LISP	Location/Identity Separation Protocol
LTE	Long Term Evolution
M2M	Machine to Machine
MAC	Medium Access Control
MEC	Mobile Edge Computing
MIMO	Multiple-Input and Multiple-Output
MLDR	Mobility Loss Detection and Recovery
MME	Mobility Management Entity
mmWave	Millimetre Wave
MNO	Mobile Network Operator
MTC	Machine Type Communication
NAP	Network Access Point
NDN	Named Data Networking
NFV	Network Function Virtualization
NP	Network Performance
OAM	Operation, Administration and Management
ONOS	Open Network Operating System
PCE	Path Computation Element

PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDU	Protocol Data Unit
P-GW	Packet data network Gateway
PIF	Protocol Independent Forwarding
PIT	Pending Interest Table
PoC	Proof of Concept
POF	Protocol Oblivious Forwarding
PTN	Packet Transport Network
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technologies
RoF	Radio over Fibre
ROHC	Robust Header Compression
RTP	Real-time Transport Protocol
SAE-GW	System Architecture Evolution - Gateway
SAP	Service Access Point
SDN	Software Defined Networking
SDO	Standard Development Organization
S-GW	Serving Gateway
SIP	Session Initiation Protocol
sNAP	Source Network Attachment Point
SON	Self Organizing Network
SR	Segment Routing
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TMN	Technology Management Network
UDP	User Datagram Protocol
UE	User Equipment
UHD	Ultra-High Definition
UMTS	Universal Mobile Telecommunication System
UNI	User Network Interface
URI	Uniform Resource Identifier
VLAN	Virtual LAN
VM	Virtual Machine

VNF	Virtual Network Function
VoLTE	Voice over LTE
VPN	Virtual Private Network
VSER	Virtual Service Edge Router
WLDR	Wireless Loss Detection and Recovery

5 Conventions

None.

6 ICN overview

6.1 Background

Information centric networking (ICN) was studied in FG IMT-2020 as an example of emerging network technologies. FG IMT-2020 produced two output documents on the description of ICN related standardization gaps and proof-of-concept technologies [b-FG IMT-2020 Gaps] [b-FG IMT-2020 ICN PoC].

ICN has been considered useful to satisfy the network requirements of IMT-2020 to support enhanced mobile broadband, massive machine-type communications and ultra-reliable low-latency communications. Research shows that ICN is a promising technology that can provide benefits for IMT-2020 networks supporting very large-scale heterogeneous devices, Internet of things (IoT) applications, new mobility models, edge computing and end device self-configuration.

ICN offers a different approach to addressing and framing data to today's Internet Protocol (IP) semantics. In IP, a source and destination addresses are used to identify the two endpoints of packet communication. The destination is almost always a unicast address and in a small number of cases an anycast address; the use of IP multicast is very limited. Inside the network, the payload of an IP packet is usually an arbitrarily framed byte stream such as transmission control protocol (TCP) or datagrams (UDP). TCP/IP assigns an ephemeral name to each packet: source IP, source port, destination IP, destination port, byte offset, byte length. These names are not reusable, nor cacheable beyond use for retransmission of lost packets. ICN's approach is to assign a re-usable name to each packet or small group of packets. This allows object re-use and peer-to-peer messaging via name without needing to resolve endpoint identifiers beforehand. ICN also bundles object authenticity with the network packets.

There are several ICN architectures being proposed to use today. The most widely known is content-centric networking (CCN) and its offshoot named data networking (NDN). NDN forked from CCN around 2012. While there are several important protocol differences between NDN and CCN, they are close enough in function so that only CCN will be described here.

Because ICN does not require resolving endpoint identifiers into locators before using a name, it opens new possibilities in machine-to-machine and IoT applications. Today, IP-based applications must use specialized rendezvous mechanisms, such as link broadcast, multicast, dynamic domain name system (DNS), multicast DNS, or session initiation protocol (SIP). This is because they must resolve an IP address for a desired name. ICN technologies remove the IP abstraction so the network can operate at the name level. This can make the network more responsive to application demands with less infrastructure.

Within an IMT-2020/5G radio access network (RAN), ICN could serve as the object transport for intra-RAN data. For example, the state of a network slice could be stored and transported as ICN data objects, so as services move between revolved Node B (eNodeB) sites its state follows in the named ICN objects.

In the ICN technology CCN, the name combines both a locator and identifier into one routable hierarchical structure. It could be thought of as routing on uniform resource identifiers (URIs), where each name segment can be arbitrary binary data not restricted to the URI syntax. At one end of the spectrum are pre-generated content names, such as for a movie. A movie service could name content with a prefix like */movie_service/superman/h264/768kbps/32kbps/English* to indicate a codec and encoding rate. Names can identify things beyond static content. A simple example would be a dynamic web service, such as */book_store/home/<encrypted_account_identifier>*, where the *<encrypted_account_identifer>* is a blob that the book store server can understand and use to generate a custom homepage. Names could also indicate a type of calculation, for example */calc/4/2/times* could return a content object with the value "8". In all these examples, ASCII names were used, but in practice name segments can be binary values, not necessarily human-readable.

6.2 Elements of ICN

ICN is usually made up of content producers, content publishers, content replicas and content consumers. A producer generates a piece of content, such as a document, photo, movie, or web page. It may have its own digital rights management (DRM) attached by the producer. A publisher packages a piece of content for use in the network. This may include pre-encoding the content to certain formats and names and signing them with a network identity. A replica distributes content from a publisher. A consumer fetches content via network names from replicas. The download process at a consumer understands the inherent security offered by the ICN, which usually allows authenticating every packet via direct signature or implicit hash chain from the publisher. This is different from today's security model, where authenticity derives from a secure connection to a replica. In the simplest configuration, one entity is a producer, a publisher and a replica for its content.

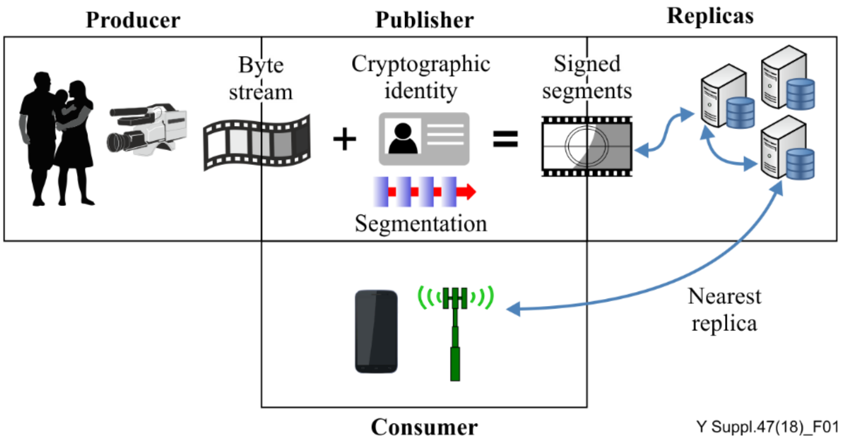

Figure 1 – Typical ICN architecture

Figure 1 illustrates the typical ICN architecture, which is referred to here to describe how an actual instance of CCN would handle these activities. This is an example of a family video service created at home, such as a video of their baby. The video camera produces video stream (e.g., MP4 byte stream). The publisher function, which may reside on the camera, home gateway, or other device, segments the byte stream to CCN content objects. For a live stream like this, the publisher would segment it to a certain number of video frames in a number of network packets (i.e., content objects). A CCN manifest tree incorporates those content objects by hashing into a single signed manifest representing the whole video segment. The video segment is stored on a first replica point, such as a home gateway. The publisher updates the movie catalogue to include the new segment, then repeats for the next segment. A consumer queries its nearest replica for the movie catalogue and segments. If the nearest replica does not have it, the request is forwarded towards the publisher until satisfied. The content travels to the consumer and is optionally cached in intermediate replicas.

As illustrated in Figure 1, a consumer may fetch content objects from any replica and still be assured that it is the correct data. This is because the manifest tree is signed by the publisher and then securely hash-linked to each content object. The consumer and replica may also opportunistically encrypt their session for privacy. The consumer may choose to only trust replicas, for example, that are enumerated by the original content publisher or are provided by the a trusted party, such as the user's carrier or cloud service.

In a second example, a cell phone producing a video could be producer, publisher and replica all in one. Because nobody would want a large number of consumers on the Internet fetching data directly from their cell phone, it could be configured to only allow the user's home media server to fetch content and then act as the authoritative replica for the Internet. The user could choose to use a carrier service (i.e., cloud-based media server) to act as the authoritative replica.

7 Standardization gaps

The following standardization gaps have been identified by FG IMT-2020:

Gap 1: Considering ICN as a protocol for IMT-2020 Network Priority: High

Description: In the existing mobile infrastructure, IP is the main transport protocol and everything is optimized around the Layer-3 of the OSI (TCP/IP) stack. However, experience has shown that there is a need to migrate to protocols which can comprehensively integrate infrastructure, transport and content. Research and development in ICN shows the possibilities to solve this problem. ICN needs further development in areas such as mobility management, end-to-end QoS, prioritization and scale to manage billions of devices, which are framework of IMT-2020 networks.

There are three possible scenarios for IMT-2020 network where ICN can be introduced:

Option 1: The IMT-2020 network using ICN as an overlay protocol

Option 2: The IMT-2020 network using IP as transport for mobility management and ICN for service delivery without an overlay. ICN routing exists on the UE and P-GW.

Option 3: The IMT-2020 network using ICN as native transport for mobility management and service delivery. ICN routing exists throughout the network.

Gap: Detailed architecture analysis of the three above options is required.

Related work: IRTF/ICNRG documents.

Gap 2: ICN – Robust header compression for air interface (PDCP) Priority: High

Description: Applicable to Options 1, 2 and 3.

Standard compression techniques, such as LZW, are not appropriate for ICN packets because many of the fields represent cryptographic octet strings and thus are not sub-string compressible.

Gaps:

1) When encapsulated in IP, there is a need to specify an ICN profile, similar to a real-time transport protocol (RTP) profile.
2) When used as a native protocol, e.g., over an ICN slice, there is a need to specify an ICN-specific robust header compression (ROHC) profile at the air interface.

Related work: IETF RFC 4995, [b-3GPP TS 36.300].

Gap 3: ICN – Mobility anchoring (ICN aware S-GW) Priority: Medium

Description: Applicable to Option 3.

Existing mobile networks have one mobility anchoring point (S-GW) so that devices can be located for downstream traffic. Each user equipment (UE) has one anchoring point and multiple service end points e.g., access point name (APN) based upon simultaneous services being accessed by the application running device e.g., visual voice mail, voice over LTE (VoLTE), mobile Internet, etc. For the IMT-2020 architecture, using ICN as a transport protocol, the ICN specifications need to be updated to support edge device anchoring. ICN is suitable for introducing new mobility models that are not tied to the anchor-based approach used for IP. This is because ICN does not require a unique source representation (egress identity).

It is necessary to modify and develop call flows for ICN based device attachment, authentication and registration with content providers. It is recommended to describe ICN operating in three different models:

1) Similar to current single anchor like a serving gateway (S-GW) and packet data network gateway (P-GW).
2) Using the closest ICN router(s) as a single anchor.
3) Distributing anchors among points of attachment.

Gap: The 3GPP model and the ITU-R 5G documents specify that a UE only has one S-GW, whereas for ICN, multiple simultaneous gateways would be required.

Related work: [b-ITU-R M.2375-0], [b-3GPP TS23.401].

Gap 4: ICN – Mobility (ICN-aware MME) Priority: Medium

Description: Applicable to Option 3.

In the existing LTE architecture, all mobility management is handled by the mobility management entity (MME), eNodeB, etc. The ICN protocol must evolve to include mobility management messages. Mobility management can be done either by the MME or something similar e.g., ICN router(s)/edge gateway. The first step for introduction of ICN capabilities can be an ICN aware MME, S-GW/P-GW, etc. and eventually replacing the GTP based model with ICN based transport functions e.g., an ICN-aware MME should allow for one of the several ICN-style mobility models.

Gap: The 3GPP TS23.401 specification specifies mobility management and attachment procedures using IP. New specifications and procedures are necessary to use ICN as a transport protocol.

Related work: [b-ITU-R M.2375-0], [b-3GPP TS23.401].

Gap 5: ICN – Protocol (ICN-aware P-GW operation) Priority: Medium

Description: Applicable to Options 2 and 3.

Description: Currently IP is used for UE attachment procedures for APN in the P-GW, which is the services attachment point. The P-GW manages IP address allocation, billing and policy enforcement, etc.

Gap: ICN mechanisms for P-GW functions such as billing and policy enforcement need to be specified.

Related work: [b-ITU-R M.2375-0], [b-3GPP TS23.401].

Gap 6: ICN – Protocol execution (slice) Priority: High

Description: Applicable to Options 2 and 3.

In the existing long term evolution (LTE) architecture, the main protocol is based on IP. However, for IMT-2020 there is a need to define how ICN protocols operate in the RAN and EPC. In the case of using a network slice, there is a need to specifically enumerate the service interfaces and how those interfaces are exposed to non-IP based protocols operating within a slice environment.

Gap: For a software-based slice environment, the ICN execution environment needs to be described, including the virtualized resources that are available and their interfaces.

Related work: Network softwariation.

Gap 7: ICN – Lawful intercept (specify what to capture) Priority: High

Description: Applicable to Options 2 and 3.

In the existing LTE network, lawful intercept messages are based on IP and these messages are taken from gateways (SAEGW, MME, HSS, etc.). ICN protocols may operate with a different model of S-GW and P-GW, such as those elements being collapsed to the base station (option 3). This may significantly affect how lawful intercept operates.

As a non-IP protocol, additional collection practices may need to be specified and implemented for a specific ICN. When gateways are distributed, lawful intercept message have to be collected from multiple egress points.

Gap: How to specify an intercept of a non-IP protocol, for example what does the packet filter look like?

Related work: [b-3GPP TS23.002].

Gap 8: ICN – Mobility and routing Priority: Medium

Description: Applicable to Options 2 and 3.

There is a need to specify routing models for ICN within an IMT-2020 environment to enable desired mobility features. During initial ICN development work, mobility was not factored. However, the IMT-2020 network will have mobility and this has to be managed for millions of devices. There are three possible scenarios for mobility:

– UE consumer mobility,
– UE producer mobility,
– ICN state transfer.

Operator maintained content is cached for intra-RAT and inter-RAT data retrieval. For example, content with the same name may exist in multiple locations, but one does not want to create multi-homed routes. Distributed routing within the RAN include,

– Certain features, such as mobile edge computing (MEC), could benefit from local dynamic routing to solve the service rendezvous problem such that a UE application can easily exploit local services.
– Disaster recovery or other edge applications could benefit from local dynamic routing.
– Similar for IoT and machine to machine (M2M) applications.

Gap: Study using the ICN routing and control for mobility management rather than the current anchoring based mechanisms.

Related work: [b-3GPP TS23.401].

Gap 9: ICN – UE provisioning Priority: High

Description: Applicable to Options 2 and 3.

ICN is a new technology that does not have the breadth of support that IP has for operations and management. In the current mobile network, the UE identity (IP address) is allocated and managed by the P-GW based upon applications (APN). When ICN is used within the carrier network, then the carrier should be able to assign a name and other ICN parameters.

Gap: Need to define a protocols and mechanisms for ICN provisioning.

Related work: [b-3GPP TS23.401].

Gap 10: ICN – Managing IMT-2020 Self Organizing Network (SON) Priority: Medium

Description: Applicable to Option 3.

SON needs to communicate between different radio, element management systems (EMSs), OSS/BSS and core network (CN). ICN does not support communication mechanisms for SON.

Gap: There is need to define the right set of ICN messages and parameters so that the SON platform is managed effectively.

Related work: [3GPP TS32.50X].

Gap 11: ICN – Operations and management (common interfaces) Priority: Medium

Description: Applicable to Options 2 and 3.

Current management platforms are defined to run over IP and manage IP. When ICN elements are introduced into the network the management protocol needs to support ICN. In Option 3, management protocols may need to operate over ICN.

Gap: The IMT-2020 architecture describes common management interfaces that need to be ICN aware.

Related work: Technology management network (TMN) documents.

Gap 12: ICN – Operations and management (SDN/OpenFlow) Priority: Medium

Description: Applicable to Options 2 and 3.

Many of today's carrier networks are managed/programmed with SDN.

Gap: Today's SDN tools need extensions for ICN.

Related work: ONOS, OpenDayLight, Open Network Foundation documents.

Gap 13: ICN – Security (authentication and encryption) Priority: Medium

Description: Applicable to Options 2 and 3.

Often each party in an ICN communication is considered to have a cryptographic identity. Should that identity be used in IMT-2020 associations or resource usage, or should it all be based on international mobile equipment identity (IMEI) or existing IMT-2020 identity?

Key resolution services: some ICN approaches use the idea of a 'key resolution service' to determine from a trusted anchor what public key a publisher should be using for its namespace. Is this needed in an IMT-2020 environment and if so how would this integrate in a carrier environment?

Gap: IMT-2000/Advanced has defined several identities for a UE. IMT-2020 is also required to support several identities for a UE. A study is needed to determine if any of these identities are suitable for ICN, or if additional cryptographic identities are needed.

Related work: [b-3GPP TS23.401], [b-3GPP TS33.401], [b-3GPP TS36.323].

Gap14: ICN – Security (encryption) Priority: Medium

Description: Applicable to Options 2 and 3.

Today, end-to-end encryption using IPSEC/TLS does not allow the carrier to intelligently manage the data (e.g., DPI, caching). ICN offers new possibilities for key exchange and encryption where the carrier can play an active role because the ICN packet can be selectively encrypted between the carrier and the remote party.

Gap: ICN sometimes uses different forms of encryption than what is found in today's IP networks. IMT-2020 should study the use of selective ICN encryption.

Related work: None.

Gap15: ICN – QoS (demand based) Priority: Medium

Description: Applicable to Options 2 and 3.

QoS is well defined in IP and Ethernet layer which is mapped to QoS class identifier (QCI). In Options 2 and 3, ICN can use a similar mapping of DSCP to support interoperability with existing transport networks. Additionally, ICN provides the possibility for new forms of QoS definition.

Gap: A study is needed on ICN-specific QoS in IMT-2020, for traffic prioritization and congestion management

Related work: [b-3GPP TS23.401].

8 Proof-of-concept

This clause describes the five proof-of-concepts (PoCs) investigated in FG IMT-2020 by several participating organizations: Cisco, Fujitsu Labs of America, Huawei, InterDigital and KDDI. These PoCs address six of the fifteen standardization gaps listed in the previous section. Clause 8.1 presents the short overview of each PoC and mapping with relevant gaps. The detailed descriptions of each PoC will follow in the subsequent clauses.

8.1 Overview and mapping with standardization gaps

PoC #1: ICN enhanced mobile video at the network edge

ICN provides a unified network and transport layer addressing content by name rather than by location. By disrupting the traditional connection-oriented communication model, ICN simplifies data delivery, mobility management and secure transmission over a heterogeneous network access. This PoC selects dynamic adaptive stream over HTTP (DASH) video delivery as a use case and shows the benefits of ICN mobility management, in-network control (rate/loss) and network-assisted bitrate adaptation for a multi-homed user device.

PoC #2: Functional chaining system in ICN

By separating contents from their location, ICN is expected to improve network efficiency and reduce the communication cost of accessing popular content. ICN principles can be applied to functions as well as to content. Named functions can then be linked to form service chains that provide optimized service delivery. This PoC illustrates such a functional chaining system to deliver real-time processed video content to a consumer.

PoC #3: End-to-end ICN service orchestration with mobility for IMT 2020

This PoC demonstrates one of the important benefits of ICN of offering seamless mobility as part of the network architecture, avoiding any specific gateway functions or tunnelling present in current 4G systems. It takes advantage of name based routing, more specifically ID/locator name space split that ICN naturally supports to offer flexibility to the mobile entities to move between administrative domains and also handling in-session mobility when they roam in a single domain.

PoC #4: IP services over ICN

This PoC highlights two quantitative benefits of delivering IP services over ICN. The first one is that of introducing the capability to deliver HTTP responses via multicast to a number of clients. This solution specifically supports changing multicast groups by forming multicast groups in an ad-hoc manner solely at the source network attachment point. The second aspect is that of the possibility to reduce service latency through the exposure of surrogate service endpoints in a fast and flexible manner. This is enabled by the exposure of HTTP-based resources through the FQDN of their providing servers. Examples for such surrogate functionality are that of choosing alternative HTTP-level streaming servers, localizing video playout to the regions where these playout points serve clients rather than needing to retrieve the content from a central server.

PoC #5: ICN transport on millimetre wave networks

To resolve problems with intermittent connectivity in a millimetre wave network, a new wireless access network has been developed in Japan that combines 40 GHz operation for outdoor networks with 60 GHz operation for mobiles to enable large data size content delivery on the gigabyte scale. CCN is used to develop a method that operates together with the millimetre wave small zone (60 GHz band) and large zone LTE in heterogeneous networks. It could therefore realize high-speed file transfer in the millimetre wave band without the user being aware of switching of bands when passing through the GATE system.

Table 1 – Mapping standardization gaps with PoC

Standardization gaps		PoC #1	PoC #2	PoC #3	PoC #4	PoC #5
1	ICN in IMT2020	✓	✓	✓	✓	✓
2	ROHC					
3	ICN S-GW					
4	ICN MME					
5	ICN P-GW					
6	ICN Slice	✓				
7	Lawful Intercept					
8	Mobility and Routing	✓	✓	✓	✓	✓
9	UE Provision	✓				
10	ICN management SON					
11	OAM					
12	SDN and OpenFlow			✓	✓	
13	Authentication and Encrypt		✓		✓	
14	Encryption					
15	QoS					

Table 1 lists the standardization gaps and matches them with the PoCs. All the PoCs addressed the topic of using ICN in IMT-2020 to deliver user services. They also addressed mobility and routing, as those are areas where ICN could deliver significant improvements compared to the current anchored mobility in LTE. These PoCs addressed six of the fifteen standardization gaps.

8.2 PoC #1: ICN enhanced mobile video at the network edge

ICN provides a unified network and transport layer addressing content by name rather than by location. By disrupting the traditional connection-oriented communication model, ICN simplifies data delivery, mobility management and secure transmission over a heterogeneous network access. This PoC selected DASH video delivery as a use case and demonstrated the benefits of ICN mobility management, in-network control (rate/loss) and network-assisted bitrate adaptation for a multi-homed user device.

It also illustrated how ICN can effectively reduce transport cost via native edge caching and multi-point/multi-source communications over the backhaul. To that aim, it orchestrated an

ICN-enhanced virtualized network backhaul and showed its utilization over time. The PoC overview is depicted in Figure 2.

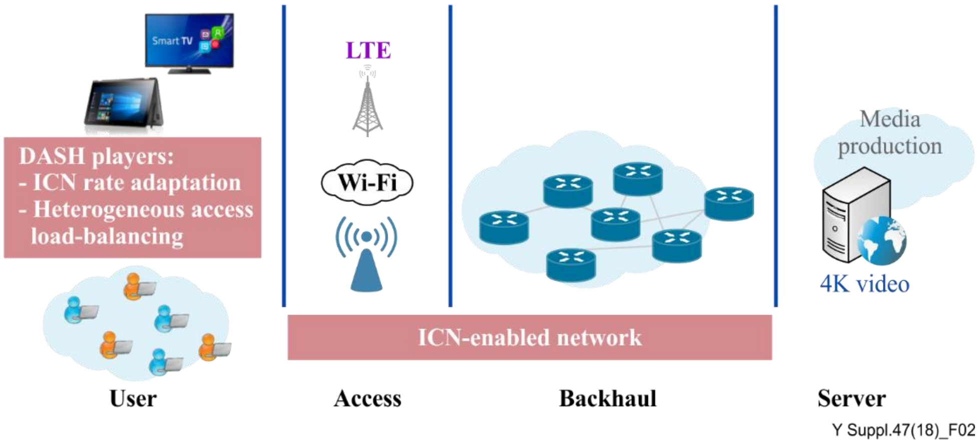

Figure 2 – ICN enhanced mobile video service PoC architecture

8.2.1 Application to IMT-2020

This PoC showed a number of benefits in adopting ICN with respect to traditional IP networks. It fills the following gaps.

1) Gap 1: Considering ICN as a protocol for IMT-2020

   ICN provided a connectionless communication model which gives us the opportunity to re-think and implement new ways of handling user mobility, secure content transmission and exploit heterogeneous access technologies.

2) Gap 6: ICN protocol execution

   This PoC deployed a virtualized network backhaul, as well as multiple clients that run a DASH video player application. It used an orchestrator to deploy and modify over the time the topology setting.

3) Gap 8: ICN mobility and routing

   Mobility is one of the most important aspects in IMT-2020 networks. IP networks fail to handle mobility in a simple and flexible way. The connectionless nature of ICN gives us the opportunity to define new solutions to tackle the mobility problem. By default, ICN naturally supports consumer mobility. To address the micro mobility of content producers we define an anchor-less protocol called MAP-Me [b-Auge2015]. MAP-Me is designed to take advantage from the name-based ICN data plane in order to promptly update routes, without waiting for updates from the routing protocol.

   Traffic generated from mobile users is prone to losses due to connection through unreliable wireless channels, such as WiFi, or to mobility events. The ICN model allows the deployment of a distributed in-network control that can be used to detect and recover such losses. In this perspective wireless loss detection and recovery (WLDR) and mobility loss detection and recovery (MLDR) were developed [b-Carofiglio2016], two protocols designed to detect losses in-network and when possible, recover them. The PoC showed how these protocols improve the performance of our ICN transport protocol [b-Carofiglio2013] and, as a consequence, the quality of experience of the user.

4) Gap 9: ICN UE provisioning

   In IMT-2020 networks a user is expected to utilize heterogeneous access technologies, such as WiFi and LTE, at the same time. ICN gives the opportunity to do this in a natural way. A user can request different pieces of content over different medium, since there is no direct connection between the user and the producer on a particular path. This PoC showed how it is possible to exploit different access technologies and switch among them, according to the client preferences. The usage of multiple connections increases the bandwidth available at the client and improves the user video experience: the DASH client asks for videos with higher quality, reducing, at the same time, the number of rebuffering events.

8.3 PoC #2: Functional chaining system in ICN

This PoC demonstrated features and capabilities of ICN to dynamically construct functional chains that deliver on numerous IMT-2020 goals. Specifically, the functional and performance advantages are highlighted and standardization gaps are identified. This PoC also included a live demonstration.

8.3.1 Abstract

By separating content from location, ICN is expected to improve network efficiency and reduce the communication cost of accessing popular content. While there are several representative ICN designs [b-Ahlgren2012], [b-Xylomenos2014], this demonstration makes use of the named data networking (NDN) [b-NDN2016] architecture (but its concepts can be applied equally to other ICN architectures).

ICN principles can be applied to functions as well as to content. Named functions can then be linked to form service chains that provide optimized service delivery. This demonstration illustrates such a functional chaining system to deliver real-time processed video content to a consumer.

As shown in Figure 3, there are multiple video sources (1, 2, 3) and multiple video processing functions (video combiner, video compression) linked by NDN routers (A, B, C, D).

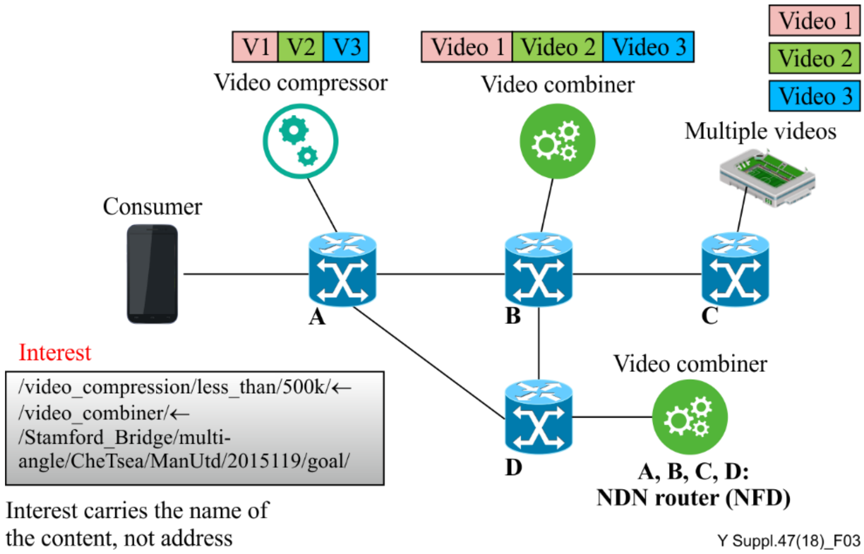

Figure 3 – Functional chaining system with ICN demonstration set-up

8.3.2 Application to IMT-2020

This PoC addressed the following gaps and illustrated corresponding advantages:

1) Gap 1: Considering ICN as a protocol for IMT-2020

ICN/NDN transport provides the foundation for creating service chains of named functions [b-Sifalakis2014] and named content (identified in the Interest request).

2) Gap 8: ICN mobility and routing

Routing optimization is shown where functions may have multiple copies in the network and each router is capable of selecting the next function node which is closer to the remaining functions / content in the request as a result of name-based function routing and the knowledge of all required functions / content for the whole chain. As shown in Figure 4, router A forwards the Interest to router B rather than router D for processing because the video combiner at router B is closer to the video content [b-Liu2016].

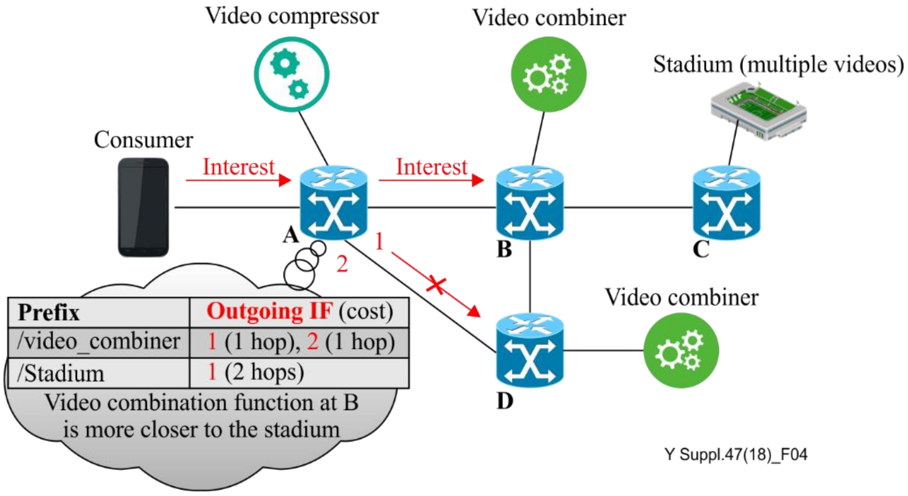

Figure 4 – Routing optimization

Once the fully combined and compressed video has been served to the original requester via router A, a subsequent Interest request received at router A for the same combined video can be handled entirely by router A due to in-network caching as shown in Figure 5.

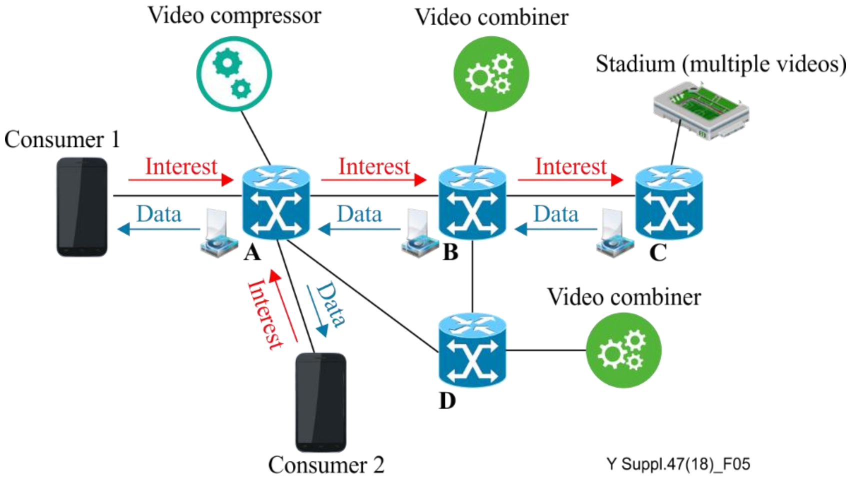

Figure 5 – In-network caching

3) Gap 13: ICN Security (authentication and encryption)

Whole-chain authentication allows the data consumer to verify every node in the service chain. Note that packet-level authentication mechanisms are not sufficient for the functional chain. The proposed whole-chain authentication prepends fixed-length hashed content to a message stack, as well as an unmodified signature (for the hashed content) to a signature stack, for each node along the chain. As shown in Figure 6, the data consumer is capable of identifying a malicious node (which is not immediately adjacent to the data consumer) [b-Bahrami2017].

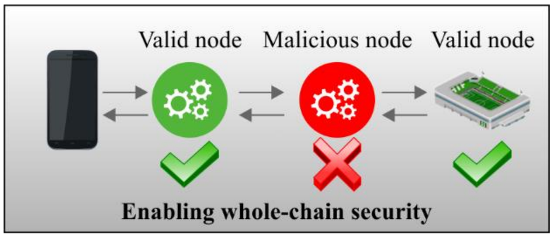

Figure 6 – Whole-chain authentication

8.3.3 Implications for standardization

The PoC addressed the above gaps, which are all candidates for standardization in IMT-2020. Notably, ICN topics are being actively pursued in the Internet Research Task Force (IRTF)/ Internet Engineering Task Force (IETF). While the PoC demonstration was focused on video service, it could be applied to any other processed data delivery scenario.

8.4 PoC #3: End-to-end ICN service orchestration with mobility for IMT-2020

8.4.1 Overview

This PoC demonstrated one of the important benefits of ICN of offering seamless mobility as part of the network architecture, avoiding any specific gateway functions or tunnelling present in current 4G systems. This PoC took advantage of name based routing, more specifically ID/locator name space split that ICN naturally supports to offer flexibility to the mobile entities to move between administrative domains and also handling in-session mobility when they roam in a single domain. Here ID binds to applications and locators bind to the ICN network entities. In addition, ID/locator name space split in ICN also enables features such as multi-homing of not only end devices but also the ability to host content and services anywhere in the ICN network to meet application requirements. In addition to the mobility benefit, this demonstration also addressed the question of enabling ICN in a 5G environment as a slice over a generic infrastructure pool and the ability to orchestrate ICN services over well-known compute and network virtualization platforms, i.e., OpenStack and ONOS.

8.4.2 Towards ICN standardization

This PoC addressed the following standardization gaps:

Gap 1: ICN as a protocol for IMT-2020 network

This gap deals with the deployment of ICN. This PoC showed the feasibility of an overlay deployment over IP over a generic infrastructure. It demonstrated this by realizing a video conferencing service over a generic infrastructure over which other ICN services can also be realized. The ICN transport was based on virtual service edge router (VSER) platform [b-Chakraborti2015] running over commercial off-the-shelf (COTS) hardware. It ran CCN as host processes, managed in a centralized manner using application-driven ICN service and network controller. Towards network slicing and dynamic realization of network functions, these host processes can also be virtualized using container or virtual machines. From a deployment perspective, VSER is an ideal platform for edge deployment such as for a central office that can take advantage of most of the features offered by ICN, which include mobility, multi-homing, multicasting and in-network computing depending on the points of ICN enablement in the service delivery chain. Feasibility of handling mobility over ICN is also considering the use of edge cloud resources to realize eNodeB functions, collocated with the cloud radio access network (C-RAN) implementation. This allows ICN to interface with heterogeneous RAT stacks such as LTE or WiFi.

Gap 8: ICN mobility and routing

Another challenge raised was the support for ICN mobility and routing scalability. This is also important considering that IMT-2020 mobility requirements [b-NGMN2015] has more demanding requirements for mobility such as to support for in-session user experience even at 1000km/h. Current mobility support in architectures like LTE is supported over tunnels terminating at specialized gateway functions in the network. This increases network cost, complexity and flexibility of network deployment and its management. ICN addresses the basic architectural issue in IP by allowing applications to bind to names, where ICN manages its resolution to a location in the network either through in-network routing or through the use of a name resolution system. With ICN, IP is a transport over which ICN protocol data units (PDUs) are exchanged. Towards mobility, this prototype takes advantage of ID/locator split that ICN naturally supports to offer flexibility to the mobile entities to move between administrative domains and also handling in-session mobility when they roam in a single domain. This removes the need for gateways or anchor nodes in the network. The demonstration was developed in the context of ICN/CCN. The demonstration showed seamless mobility of an end user generating live video being consumed by one or more participants with session interruption of ~100ms after each handover. Centralized orchestration applying SDN/NFV principles in ICN provides resource and topology abstraction to applications to inter-connect service resources to the user requests in an efficient manner exploiting compute, storage and connectivity resources of an ICN transport. Specifically, scalability of centralized routing within a domain is addressed by conducting routing in the domain using locators and limiting name to locator binding only to the edges of the network, departing from the standard SDN method of setting per-flow rules at every hop. Further the caching of the name to locator binding in the network edge reduces the need to resolve popular Interest flow in a centralized manner.

Gap 12: Operations and management (SDN/NFV)

SDN and network function virtualization (NFV) based ICN transport is very powerful as it achieves the objectives of realizing application driven networking. SDN virtualizes ICN resources i.e., ICN router's connectivity, compute, cache resources to applications to request, expand or shrink resources dedicated to it on the ICN forwarders. NFV allows the management of the service functions in the forwarders, while interacting with the SDN controller on its status. This PoC demonstrated the use of centralized programmability of the CCN transport using OpenStack and ONOS. Both these frameworks had been adapted to an ICN/CCN context. OpenStack was used to manage ICN service function (VMs executing specific in-network service logic), provisioning them on demand by respective service controller over any VSERs. ONOS was extended to execute multiple ICN controllers to manage foundational functions such as managing the virtual topology as viewed by applications, proxy the signalling from the ICN forwarders and de-multiplexing to appropriate service controllers for further actions and provisioning the forwarding information base (FIB) rules as required by application controllers.

8.4.3 System architecture

Figure 7 shows the system level view of the PoC. ICN UEs connect to the ICN virtual service edge routers (VSERs) over a single hop IP link (which can also be replaced with a WiFi or LTE access stack implementation). VSER runs on a COTS server and implements a CCN forwarding daemon along with the feature of enabling dynamic interaction with any service function orchestrated by the service controllers on these nodes. Three kinds of service functions are employed in our prototype: 1) to support basic network services like discovery and naming, e.g., the service access point (SAP) on the VSERs aids with that; 2) control plane functions to aid network services like mobility; 3) to aid application services, such as in this case the A/V conferencing service.

The VSER nodes are overlaid over IP, whose state is orchestrated by OpenStack and ONOS. ONOS implements multiple controllers towards this demonstration: 1) the ICN network controller abstracts the VSER nodes to applications, to enable connectivity between service functions, UE and the content resources; 2) the mobility controller implements the domain level dynamic name resolution function, through which the mapping of a identifier to one or more locator names are managed;

3) the video conference controller manages the control and Interest forwarding logic to interconnect the audio/video flows from multiple participants. OpenStack is used to manage the operation of provisioning and deleting virtual machines executing specific control plane of application logic in the VSERs; this is conducted through APIs exposed by OpenStack by a custom orchestrator called the service manager.

ICN services are orchestrated by the service manager. It implements the video conferencing service controller through which a user requests to provision a conference instance. The A/V controller in the service manager requests OpenStack to provision the relevant service function in the context of the given service. Once these services are active, they update the application controllers in ONOS to initiate appropriate routing rules to interconnect the services with one another and conduct dynamic routing when events such as participants join and leave the conference.

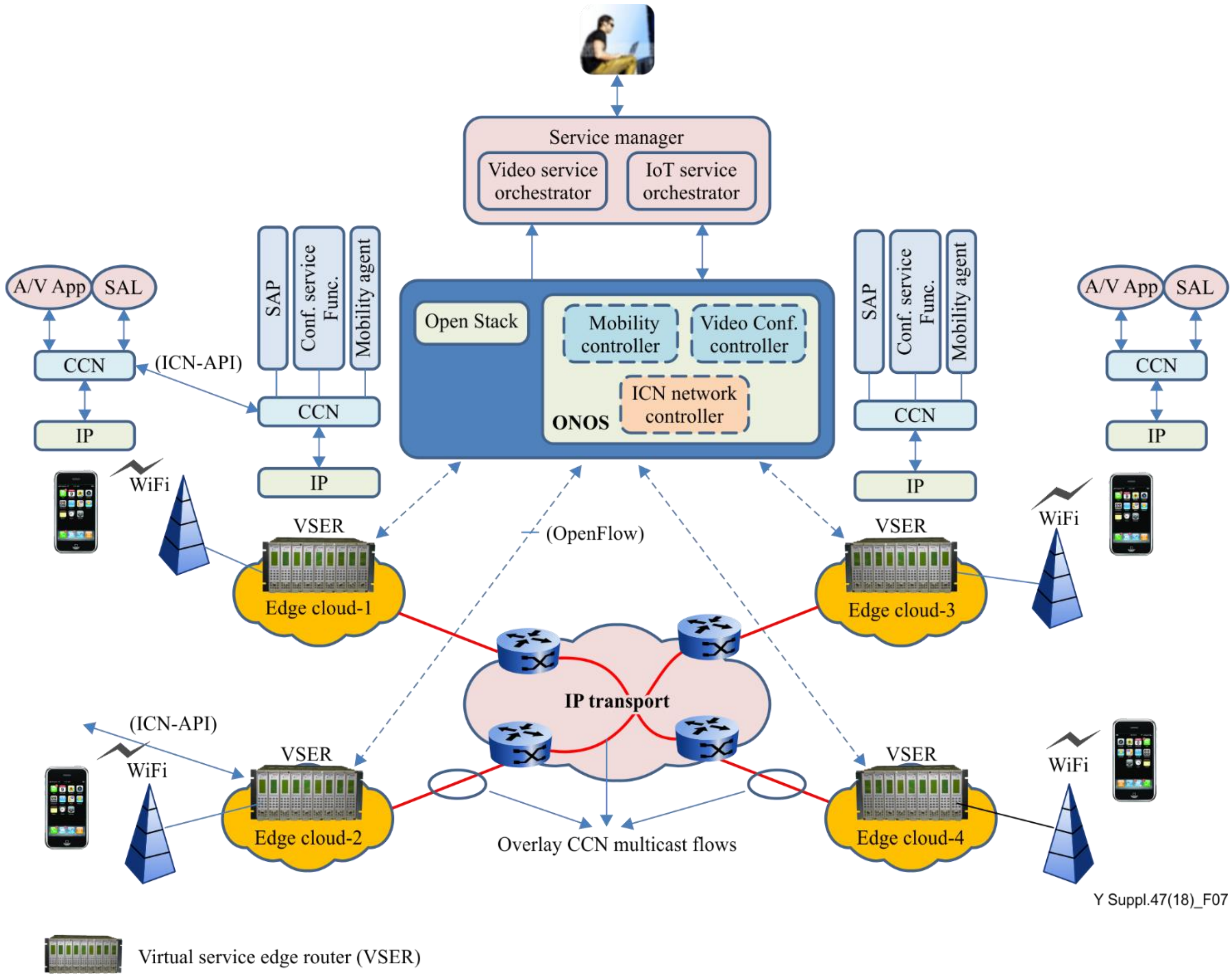

Figure 7 – VSER system architecture

8.4.4 Mobility solution

The mobility solution implemented to aid seamless producer mobility in ICN/CCN for this demonstration is described in [b-Azgin2016]. Though the mobility handled by the VSERs are handled in an IP overlay manner, with appropriate control plane support, an ICN application's producer mobility can be handled in the ICN layer, without underlay mobility support. The efficiency of such overlay mobility depends on the specific approach applied to re-connect UE to the new point-of-attachment (PoA) after handoff and the cross layer communication efficiency between the ICN and L2/L3 when a handoff is triggered and specific ICN layer mobility strategy. A "make-before-break" network-based mobility approach is applied where the IP network binding of the new PoA is provided to the UE before the handoff. This is based on the current practice of UE providing the candidate list of base stations based on the signal quality perceived from its current location.

For seamless mobility, late binding approach [b-Azgin2014] is applied using forwarding label insertion [b-Azgin2016] in the CCN Interest as a result of name resolution applied at the ingress PoA which swapped at the producer end PoA with a new forwarding label, if required, thus achieving seamless mobility. Through this PoC the feasibility of a mobility-as-a-service realization [b-Azgin2016] is also demonstrated where any application can request the ICN mobility control plane to handle mobility for a name prefix. As a result, all the flows under that name will be provided seamless mobility support. Further mobility service controller itself is service aware, by managing multiple service profiles and managing the service names for which mobility has been requested for each profile.

The prototype is developed to show the feature of realizing mobility as a service. Here any application can request mobility to flows under its name prefix by requesting an agent function in the UE to register it for mobility service offered by the network. The network then creates appropriate mobility state in the VSER nodes and the mobility controller to handle the Interest flows with appropriate mobility support.

8.5 PoC #4: IP services over ICN

This PoC aimed at delivering IP-based services over an ICN-based routing solution within a single operator or across collaborating operators at higher efficiency and lower latency than possible in today's solutions. It provided a possible migration approach for the introduction of ICN, enabling full backward compatibility of IP-based services, applications and user equipment, while also offering the qualitative and quantitative performance advantages of ICN. Specifically, it enabled the multicast delivery of HTTP request responses in scenarios such as those of personalized viewing of video content. Furthermore, it also enabled the reduction of experienced latency through the flexible placement as well as quick activation of surrogate HTTP servers within the network and closer to the end user. It did not rely on DNS-based methods, overcoming the inherent limitations of DNS-based indirection in terms of scalability, dynamicity and operational assurance, while piggybacking on the proliferation and deployment of SDN-based transport networks.

This PoC showcased the easy integration of ICN networks with existing HTTP based applications and demonstrated multicast gain in a personalized video scenario, which could include on-site human users as well as emulated users in a remote data centre.

This PoC specifically addressed the following gaps:

1) Gap 1: Considering ICN as a protocol for IMT-2020

   This PoC was based on a native ICN solution that directly and efficiently integrated with SDN without any extensions needed to current OpenFlow specifications (version 1.2 or later). As such, it provided the capability for future native ICN applications. In addition, however, it provided a strong migration path for IP-based services, enabling any IP-based service and application to run on our network as well as connecting standard IP-based user equipment to the attachment points of our solution, while utilising the multicast and information routing capabilities of ICN to quantitatively improve on network utilization and latency.

2) Gap 8: ICN mobility and routing

   This PoC provided an answer to mobility and flexible routing in that direct path routing was provided, based on handover triggers delivered to the PCE and path/server resilience

3) Gap 12: SDN and Openflow

   This PoC used SDN to control the ICN underlay to transport IP services. As described above, it did not require any modifications to OpenFlow 1.2 or later.

4) Gap 13: ICN security

This PoC provided the ability to securely route HTTP service requests to authorized servers, therefore preventing data leakage often occurring in CDN-based redirections. Furthermore, it supports secure HTTP through providing an HTTPS interception proxy at the ingress and egress NAP (or GW), requiring a certificate sharing agreement between operator and content providers. Note however that this security improvement is complementary to the main idea of the PoC which is to use HTTP on top of ICN.

8.5.1 ICN over SDN

In [b-Trossen2012], individual information items are identified by names or statistically unique fixed size labels which in themselves hold no meaning. Multiple information items can be placed in a scope which is also named in the same manner and can be nested within other scopes thus creating graphs of information which allow computations leading to specific information elements.

Information elements are published and subscribed to. The semantics are realized by the rendezvous (RV), topology management (TM) and forwarding (FN) functions. RV matches requests and information elements. The TM then creates a communication path to the subscriber and the FN forwards the information along path. The path is identified by a forwarding identifier (FID) that represents the path information as a bitfield information in which each bit signifies a specific link in the overall network. With that, a simple AND and COMPARE operation at each forwarding node (e.g., SDN switch) is performed to test the membership of the node's output port (identified through a specific bit position in the bit field).

Recent developments [b-Reed2016] have shown that the aforementioned ICN forwarding can be directly implemented in OpenFlow controlled SDN switches. This realization relies upon the fact that SDN switches, from OpenFlow v1.2 (ONF, 2011), can implement flow-rule matching using an arbitrary bit-mask across a number of header fields, including IPv6 addresses and Ethernet MAC addresses. Such arbitrary bit-mask matching is directly equivalent to the necessary AND and COMPARE operation when considering a bit-mask with only the specific output port's bit position set. Consequently, it is possible to implement the ICN forwarding using SDN switches if the FId is inserted into arbitrary match capable fields such as the IPv6 addresses and/or the Ethernet MAC addresses. This allows a FID length of 256-bits if the IPv6 header is used or 352-bits if using both IPv6 and MAC headers, while solutions have been developed to overcome this size limitation in larger networks. Through the use of a unique Ethernet VLAN ID, it is possible to separate the ICN encoded traffic from conventional Ethernet/IPv6 traffic and thus integration with existing deployments is possible.

8.5.2 IP over ICN

The intention of our system is to preserve the perception of an IP-based autonomous system towards any connected peering network through standard IP-based protocols, while exposing an IP-based interface to attached user devices as well as service providers. With this, our architecture does not impose any changes to existing user and server (as well as data centre) equipment, while enabling the full application base of today's Internet. Nonetheless, the provided network attachment points can expose native ICN interfaces that would enable native ICN applications for future ICN use cases.

The translation of IP-based communication, either directly at the IP or the HTTP level, is realized at the network access point (NAP) placed towards the user or server equipment (both denoted as UE), while the ICN gateway provides a translation towards peering IP networks, if required. Appendix I provides more detail as regards to the operations for translating HTTP exchanges into an ICN-compliant message exchange with lowest delay possible. In general, the request-response protocol of HTTP is translated into a publication of the encapsulated HTTP request at the client-facing NAP towards the fully qualified domain name (FQDN) of the HTTP server, while the client subscribes to the response URL in full. The server-facing NAP, in turn, will have subscribed to all FQDNs exposed at its local IP interfaces, therefore receiving any request as intended. As a consequence, it will receive any such publication and forward the HTTP request to the locally connected server. Upon receiving a response from the server, it is published by the server-facing NAP, in turn being received by the client-facing NAP. The optimizations realized in our solutions allow for such operations akin to HTTP request exchanges, i.e., with initial (domain-local) DNS-like resolution followed by efficient direct path exchanges between client and server, while enabling the possibility to form multicast responses for requests for the same resource and arriving at the quasi-same time. More information can be found in Appendix I.

8.5.3 Benefits of ICN solution

The PoC highlights two quantitative benefits of our solution. The first one is that of introducing the capability to delivery HTTP responses via multicast to a number of clients. It is appreciated that the nature of such multicast delivery is likely to change from request to request due to the unsynchronized nature of the HTTP requests, nonetheless, our solution specifically supports this aspect by allowing to form multicast groups in an ad-hoc manner solely at the NAP and based on the path information of the individual clients only. No specific signalling is required for the multicast support since a mere binary OR operation over all member of the multicast group suffices, such operation can easily be done for another set of multicast responses in the case of another request, again at no additional costs for signalling.

The second aspect is that of the possibility to reduce service latency through the exposure of surrogate service endpoints in a fast and flexible manner. This is enabled by the exposure of HTTP-based resources through the FQDN of their providing servers. Through an authoritative registration interface to the ICN routing solution, our PoC can enable such surrogate endpoints within the network at speeds of less than 1 s, therefore enabling the service completion from a possibly closer endpoint than the one originally being chosen. Examples for such surrogate functionality is that of choosing alternative HTTP-level streaming servers, localizing video playout to the regions where these playout point serve clients rather than needing to retrieve the content from a central server.

With respect to mobility, the path management of the PoC allows for recalculation of path information in the case of mobility, e.g., triggered by a handover event. Through replication of the path computation element (PCE), the path computation can be regionalized, further reducing the delay for recalculation. Nonetheless, in typical mobility scenarios, similar signalling delays are observed as for anchor point approaches. However, this recalculation ensures direct path data transfer, leading to a reduction of path stretch compared to anchor point approaches.

On the device-local link, there are no direct benefits of our solution, similar to many mobile edge cloud solutions which mainly focus on the access network rather than the access link per se.

8.5.4 Integration with IMT-2020

From the above it is clear that once SDN is integrated into IMT-2020, integrating ICN-based solution is a simple matter of interfacing the TM with a standard SDN controller, while relying on OpenFlow-compliant proactive rule insertion as outlined above and in Appendix I. Other than an SDN capable network, the network only requires NAP close to the clients and servers. While a 'close' deployment could be in customer premise equipment, other suitable locations are natural aggregation points, such as a serving gateway or a local GW (such as BRAS in fixed line networks) for the client and with a PDN gateway for the server.

8.5.5 Further study and possible standardization

The following areas will benefit from standardization:

– ICN is integrated over SDN through native operations of OpenFlow (1.3) switches over certain e.g., IPV6 and or Ethernet MAC header fields. The specific fields and their location / significance will have to be standardized.

– For the network access points the following functions need to be defined:
  - The hashing function performed over the domain names (i.e., URL).
  - The trigger events which cause the sNAP to register a service.
  - Control signalling necessary to implement RV, TM and FN functions.
– Namespaces or both HTTP and IP mapping.
– Signalling to support path management with topology changes.
– Signalling to support network mobility.

8.6 PoC #5: ICN transport in millimetre wave networks

Academia and industries in Japan have jointly developed and successfully implemented a 40 GHz[1] and 60 GHz[2] waveband-based high-throughput wireless access network for large-scale data content distribution. This system provides a way to introduce a high-throughput communication service to IMT-2020 using millimetre wave (mmWave)[3]-based wireless systems. The system also enables efficient use of the mmWave communication band, which is much less crowded than the wavebands below 6 GHz. Figure 8 shows the schematic overview of proposed wireless network.

[1] The 40 GHz wave band is a licensed band that is available for high-density applications in the fixed service defined in ITU WRC-2000 (World Radio Communication Conference).

[2] The 60 GHz wave band is an unlicensed band that can be used worldwide. In Japan, a band between 57 and 66 GHz is available.

[3] Millimetre waves are usually understood to be waves with operating frequencies above 30 GHz and wavelengths that are measured in mm.

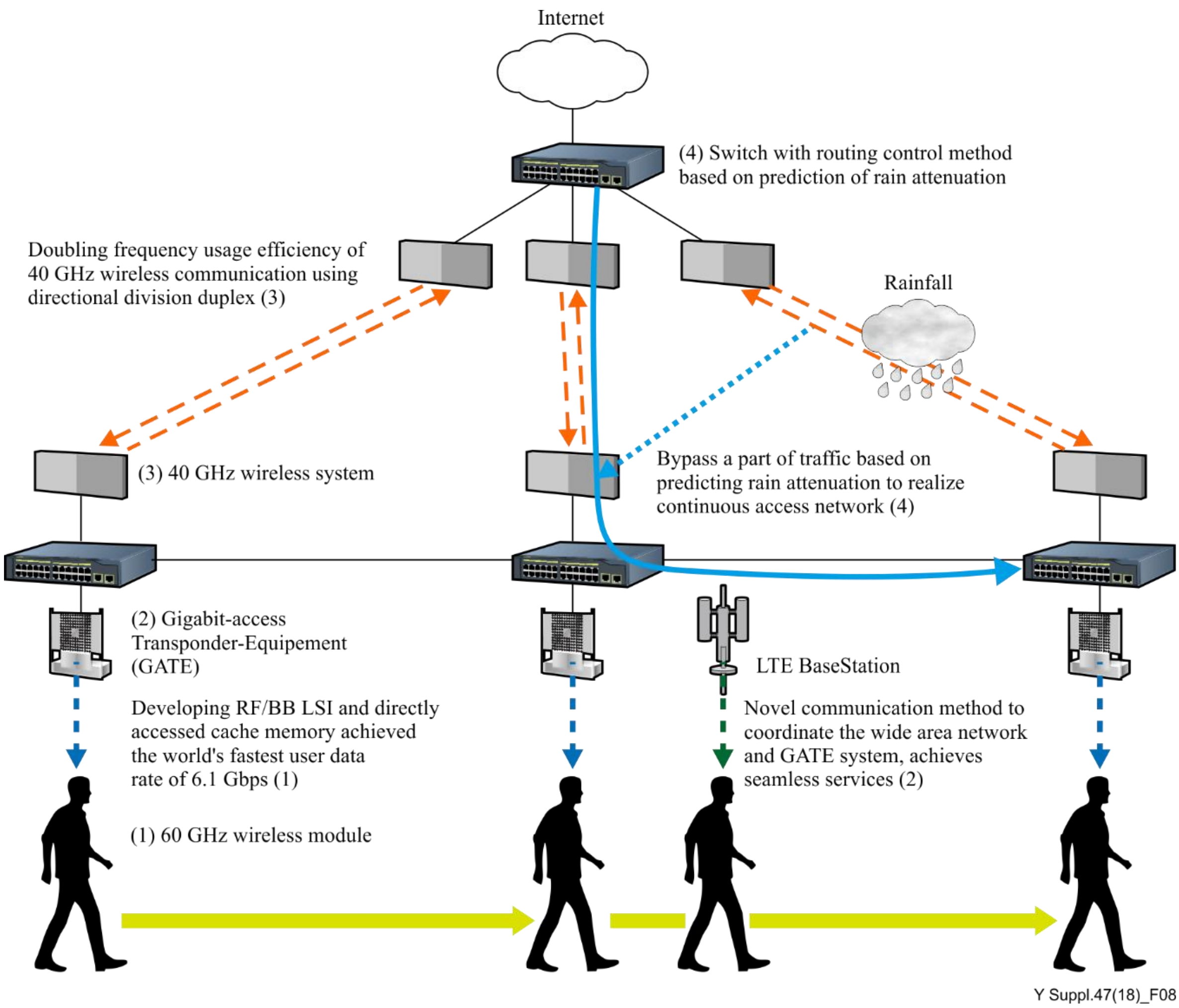

Figure 8 – Schematic overview of proposed wireless network

8.6.1 Background

The ever-increasing levels of wireless-communication traffic in recent years have consequently led to increasing demand for more communication frequencies. Utilization of the mmWave band represents a key technology for the development of the heterogeneous networks (HetNets)[4] that will be used for 5G cellular networks. However, the application of mmWaves to mobile communications is generally considered to be difficult because of the short communication range associated with these waves as a result of the high attenuation of radio power in the mmWave band. For outdoor applications of mmWaves in particular, one major difficulty is how to avoid the effects of rain, which can dramatically reduce the transmitted radio-wave power. For mobile applications of mmWaves, the significance of this problem is that network operators must strive to avoid the effects of low data throughput in commercial mobile devices with maximum data rates of several hundred Mbps, which are much lower than the multi-Gbps data rate of a typical mmWave-based wireless device, while also increasing frequency usage efficiency using multilevel modulation in these wireless devices. The technical detail of the PoC is given in Appendix II.

[4] A HetNet is a network that is used to connect computers and other devices with different operating systems and/or protocols. An example of the application of millimetre wave technology to small-cell networks can be found in: http://search.ieice.org/bin/pdf_link.php?category=B&lang=E&year=2015&fname=e98-b_3_388&abst=

9 Recommendations to parent standardization organization

The emerging network technologies group within FG IMT-2020 has studied, in particular, the applicability of ICN to address the IMT-2020 challenges. Together with Gap 1, the following three deployment options have been described: (1) over-the-top, (2) continue using IP as transport for mobility management and ICN for service delivery without overlay and (3) using ICN as native transport for mobility management and service delivery. Option (1) realizes no inherent benefits for IMT-2020 as it is purely over-the-top. Option (2) allows incremental introduction of ICN to carrier networks, which can be viewed as the most likely near-term use of ICN within IMT-2020. Option (3) requires further development of ICN and IMT-2020 standards to use ICN natively in place of IP transport.

ICN may offer technological benefits for realizing IMT-2020 goals. It is recommended that the ITU-T Study Groups continue investigation of ICN and promote more in depth study of ICN inside IMT-2020 networks, particularly, as a new service delivery platform that can unify many different requirements of IoT, edge computing and content delivery.

Option (2) makes the use of ICN visible to the IMT-2020 network so it is not simply a bit-pipe for this new technology, but a participant. The use of ICN to replace IP as the transport protocol within IMT-2020 is still a stretch goal within the 2020 timeframe. While it is an interesting research area, it is believed that the current effort should go towards option (2).

Additional references related to ICN can be found in [b-ITU-T Y.3033] and [b-ITU-T Supp 35];

The FG IMT-2020 ICN team recommended the following actions to ITU-T Study Group 13, Question 22:

1) Some gap areas have had no additional development or evaluation and these topics may not receive necessary attention without encouragement from the IMT-2020 community. These include: lawful intercept, OAM and billing. Existing communities may work on other areas, such as QoS and routing, but that work would benefit from IMT-2020 community input on key design criteria.
2) ICN and other non-IP protocols should be considered in common procedures. ITU-T SG13 is appropriate for recommendations that ensure forthcoming procedures support non-IP protocols.
3) ICN incorporates producer identities in network communications, usually via a public key cryptosystem and thus includes public key identities. ITU-T SG13 should evaluate how these identities related to IMT-2020 systems, if at all and form appropriate Recommendations.
4) Current ICN PoCs have focused on enhanced mobile broadband (eMBB). Additional ICN PoCs and evaluations should look at the IoT and ultra-low latency 5G topic areas.

Appendix I

PoC #4: IP services over ICN – Technical details

I.1 Network architecture

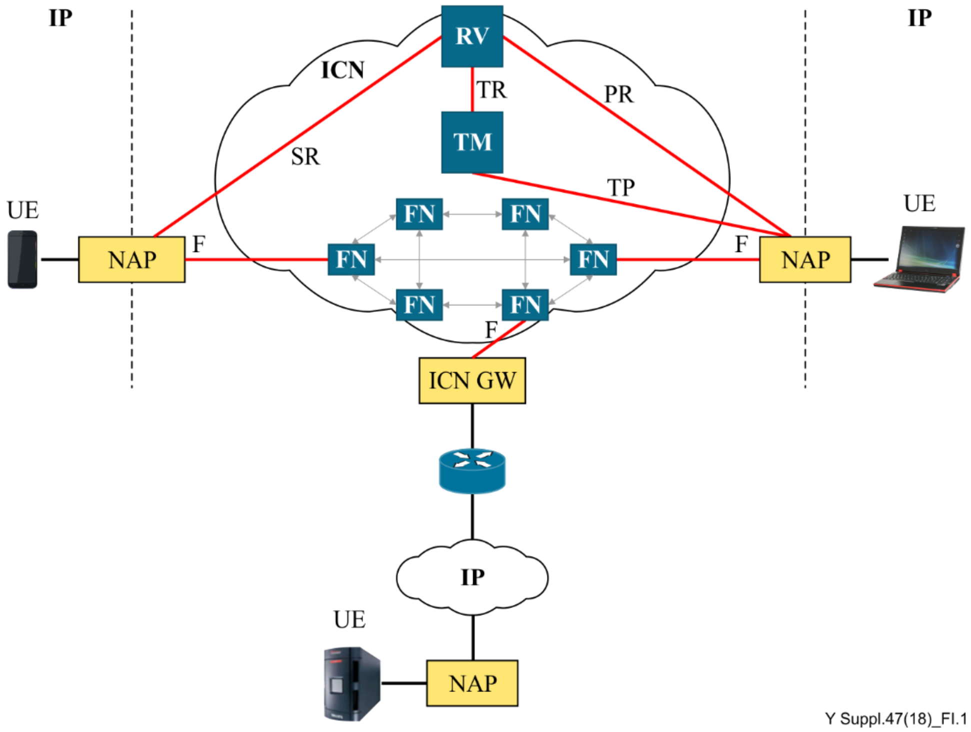

Figure I.1 – IP over ICN network architecture

Inside the ICN network, the core network functions as outlined above are realized, namely the rendezvous (RV), topology management (TM) and forwarding (FN) function. Although implementable over general L2 networks, in most deployments an SDN-based forwarding solution, based on the BF-based forwarding as presented in clause 2.2 is assumed and is the basis for our demonstration. The combined RV and TM functions fulfil the more traditional path computation element (PCE) role found in SDN environments. Figure I.1 presents the various elements of our architecture.

In the case of services across multiple domains, the establishment of a single domain IP-based autonomous system in Figure I.1 reduces this case to that of a standard inter-domain IP-based operation. In other words, a service request stemming from a cNAP in one domain will be sent via the ICN GW of the originating domain, governed via standard border gateway protocol (BGP) mechanisms, to the receiving domain. If this domain is another IP-over-ICN domain, the request will enter through the ICN GW of the receiving domain and will be forwarded accordingly within the network, as defined by the operations in our PoC.

I.2 Showcase proof-of-concept

The demonstration to run IP services over an ICN-based infrastructure and leveraging the novel coincidental multicast concepts for HTTP traffic requires a deployment which allows showcasing of exactly this. Figure I.2 illustrates the topology of the test-bed to demonstrate the benefits of the proposed solution. All IP endpoints (both clients and servers) are depicted with grey squares and their NAPs with blue circles; each NAP serves exactly one IP endpoint. The Mininet platform was used in this topology to construct a cluster of 10 IP endpoints acting as clients requesting content from a server which located at the centre bottom in Figure I.2. This IP endpoint is labelled as

"Apache Server" and serves *http://video.point* to the Mininet clients. Another IP endpoint and its NAP is depicted in the bottom left, next to the RV / TM, which acts as a trigger client to start the experiment. All yellow circles are pure ICN forwarding nodes with no other functionality than connecting the neighbouring nodes.

The content offered by the server is an MPEG DASH video which allows streaming of a video via HTTP. To start the experiment the Gstreamer client issues the initial HTTP request to http://video.point/stream.mpd which triggers a dedicated software, running on the NAP serving video.point, to send an 'out-of-band' control message to all emulated clients notifying them to start requesting the stream.mpd file too. This mimics a group of clients that happen to watch the same content at roughly the same time.

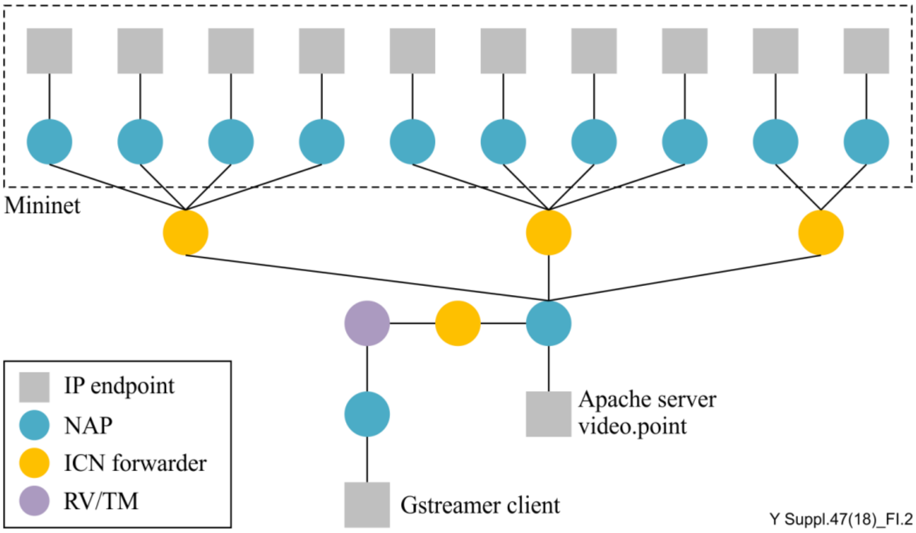

Figure I.2 – Test-bed topology with 10 emulated clients

In terms of hardware and software, the deployment is based on COTS x 86 machines with Debian 8.3 installed. An unmodified Gstreamer client Version 1.4.4 was used together with an unmodified Apache web server. The MPEG DASH video was encoded with publicly available encoding and packaging tools.

Appendix II

PoC #5: ICN transport in millimetre wave networks – Technical details

To resolve the above problems, researchers in Japan have developed a new wireless access network that combines 40 GHz operation for outdoor networks with 60 GHz operation for mobiles to enable large data size content delivery on the gigabyte scale. Using CCN[5], they have developed a method that operates together with the mmWave small zone (60 GHz band) and large zone LTE in HetNets [b-KDDI2015]. High-speed file transfer was realized in the mmWave band without the user being aware of switching of bands when passing through the GATE system.

They had previously developed experimental 60 GHz wireless complementary metal -oxide-semiconductor (CMOS) large-scale integrated circuits (LSIs) that operated with a data rate of 6.3 Gbit/s in the physical (PHY) layer in 2012 [b-Sony2012]. Now, they have developed a 60 GHz wireless module with high frequency usage efficiency, i.e., a data rate of 6.57 Gbit/s in the PHY layer that uses a 2.16 GHz bandwidth, based on the use of a 6 dBi slab-waveguide antenna, a 65 nm CMOS 60 GHz direct-conversion radio-frequency (RF) LSI and analogue circuit with 40 nm CMOS process that includes a 2.3 GSample/s 7-bit analogue-to-digital converter and a 40 nm CMOS baseband (BB) LSI that incorporates a media-access control (MAC) layer and PHY layer that uses the above analogue circuit and rate-compatible low-density parity-check (LDPC) codes[6] with code rates of 14/15 and 11/15. The design of this 60 GHz wireless module is based on the first draft of the IEEE802.15.3e[7] standard. They also developed a file transfer system with a high cache memory capacity that can be accessed directly from the wireless module with very high throughput. A 60 GHz wireless transfer system using the developed wireless module and file transfer system demonstrated the world's fastest user data rate of 6.1 Gbit/s (which can transfer a 1 GB file in 1.3 seconds). The system enables users to receive large quantities of data in moments, without the low data throughput limitations of current commercial mobile devices.

We have established an actual system that allows multiple wireless systems (hereafter called the GATE systems) installed adjacently to each other to be operated independently without interference to demonstrate the high throughput and spatial isolation abilities of the 60 GHz wave-based wireless devices, e.g., a ticket gate at a train station.

A high-gain slot-array antenna (using approximately 1000 elements in experiments) that enabled spatial isolation was developed. In addition, the radio waves do not spread out and are confined for more than 10 m in a cylindrical service area.

In the scenario where users pass through the communication area within a short period of time, Sony has also implemented a MAC protocol on the RF-BB LSIs, enabling reduced link-set-up times that allow users to start communications within 2 ms or less. JRC has integrated these technologies to form the GATE system.

Figure II.1 features photographs of the 60 GHz GATE wireless system.

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[5] CCN is a future protocol that is currently being discussed by the Internet Research Task Force (IRTF) as a replacement for the Internet protocol (IP).

[6] Rate-compatible LDPC codes are LDPC codes that were designed to enable decoding using a single decoder.

[7] IEEE 802.15.3e is the next-generation 60 GHz wave-based wireless communication standard with a maximum PHY data rate of 100 Gbit/s and a maximum link-set-up time of less than 2 ms and is currently being discussed.

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Figure II.1 – Photographs of the 60 GHz GATE wireless system

To locate the service area for the 60 GHz GATE system, which is a small portable access point, in arbitrary positions in the large zone as quickly as possible, easy installation-type radio link systems to accommodate GATEs are advantageous. They performed a successful field demonstration of an example configuration that allowed a combined operation of the 60 GHz band GATE system and the 40 GHz band wireless access system with the maximum link length of 1 km or more with 1 Gbps-class speed.

In the 40 GHz band wireless access system used here and shown in Figure II.2, the directional division duplex (DDD) system was adopted to perform simultaneous two-way communication on the same frequency and the same polarized wave, rather than the conventional frequency division duplex (FDD) or time division duplex (TDD) methods; DDD doubled the frequency utilization efficiency in principle. The realization of DDD was only enabled by full use of high-isolation between transmitting and receiving antennas arranged in parallel and cancellation technology of transmitted signal leaked in the circuit.

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Figure II.2 – Photographs of the 40 GHz wireless system using DDD

Localized torrential rainfall can lead to the disconnection of mmWave links, because mmWaves are attenuated by water. A routing control method that is based on the prediction of rain attenuation avoids potential drops in the communication capacity of mmWave access networks caused by rainfall. When the area of rain is advancing towards the mmWave access network, the routing control method predicts the mmWave links that will be affected by the rainfall and then selects alternative mmWave links to replace them. A proportion of the network traffic is then passed to the selected links proactively to reduce these drops and ensure the communication capacity of the access network.

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