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TECHNICAL REPORT

Reconfigurable Radio Systems (RRS); Feasibility study of a Radio Interface Engine (RIE)

Reference

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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 - APE 7112B
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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Reconfigurable Radio Systems (RRS).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document addresses the efficient acquisition and management of context information and suitable equipment configuration in a heterogeneous radio environment. In particular, an eco-system within the equipment is defined in order to achieve this objective.

NOTE: An eco-system may comprise entities such as Context Information Acquisition Entity, Context Management Entity, Configuration Management Entity, Flexible Modulation Entity, and others. Context information may typically comprise information on the heterogeneous radio environment (e.g. which RATs are available), location information, etc., including information gathered from sensors.

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] ETSI TR 103 062 (V1.1.1): "Reconfigurable Radio Systems (RRS); Use Cases and Scenarios for Software Defined Radio (SDR) Reference Architecture for Mobile Device".

[i.2] 3GPP TR 22.891 (V14.2.0): "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Feasibility Study on New Services and Markets Technology Enablers; Stage 1 (Release 14)".

[i.3] I. Siaud, A.M. Ulmer-Moll, H. Peng, S. Nanba and K. Moriwaki: "C/U-plane splitting architectures and Inter-RAT management for Radio Reconfigurable Systems", ETSI workshop on future radio technologies-air interfaces, January 2016.

[i.4] Giuseppe Bianchi, Pierluigi Gallo, Domenico Garlisi, Fabrizio Giuliano, Francesco Gringoli, Ilenia Tinnirello: "MAClets: active MAC protocols over hard-coded devices", in Proc. of the 8th international conference on Emerging networking experiments and technologies (CoNEXT '12), Pages 229-240, Nice, France. December 10 - 13, 2012.

[i.5] Dario Sabella, et al.: "Preliminary PoC evaluation in Flex5Gware", Deliverable D6.1 (section 10), H2020-ICT-2014-2 project Flex5Gware (Grant agreement no. 671563) June 2016.

[i.6] Dario Sabella, et al.: "Preliminary PoC evaluation in Flex5Gware", Deliverable D6.1 (section 9), H2020-ICT-2014-2 project Flex5Gware (Grant agreement no. 671563) June 2016.

[i.7] Ronald Raulefs, et al.: "The 5G Localization Waveform".

[i.8] I. Siaud, A. M. Ulmer-Moll: "Green Oriented Multi-Techno Link Adaptation metrics for 5G Multi-Techno Heterogeneous Networks", Eurasip Journal, Special Issue on Evolution of Radio Access Network Technologies towards 5G, April 2016.

[i.9] ECC Report 244 (2016): "Compatibility studies related to RLANs in the 5725-5925 MHz band".

[i.10] Commission Implementing Decision (EU) 2018/1538 of 11 October 2018 on the harmonisation of radio spectrum for use by short-range devices within the 874-876 and 915-921 MHz frequency bands.

[i.11] Commission Implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC updating harmonised technical conditions in the area of radio spectrum use for short-range devices (notified under document C(2019) 5660).

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

context information: any information that is used to describe:

- the characteristics of the radio signal at given circumstances such as time, frequency, location, and orientation by a measuring device;
- what impacts the characteristics of the radio signal by the measuring device at a given time, frequency, location, and orientation;
- the circumstances themselves, such as time, frequency, location and orientation.

EXAMPLE 1: Received signal strength of the radio signal.

EXAMPLE 2: Awareness of a rain that hinders the radio signal reception under the potential circumstances.

correlated KPIs: performance indicators having correlation with each other

EXAMPLE: A high spectral efficiency results in a higher throughput of the system.

model based data set: statistical distribution describing a data set consisting of prior measurements e.g. by the mean and the variance.

EXAMPLE: Gaussian distribution $N(\mu, \sigma^2)$ with the mean μ and variance σ^2.

uncorrelated KPIs: performance indicators having no correlation with each other

EXAMPLE: The KPI delay of the transmission of a certain data package (latency) is uncorrelated with the KPI spectral efficiency of a dedicated waveform.

NOTE: The different KPIs could be correlated by considering constraints. Such constraints could be e.g. a certain SNR that may require repeated transmissions that will lead to a higher delay.

3.2 Symbols

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

BS_1 Base Station 1
MT_1 Mobile Terminal 1

3.3 Abbreviations

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

3D	Three dimensional
API	Application Programming Interface
CDC	Country Determination Capability
CEPT	European Conference of Postal and Telecommunications administrations
D2D	Device-to-Device
DFS	Dynamic Frequency Selection
EC	European Commission
ECC	Electronic Commications Committee
EU	European Union
FEC	Forward Error Correction
FPGA	Field Programmable Gate Array
GNSS	Global Navigation Satellite Systems
GPP	General Purpose Processors
HW	Hardware
IP	Internet Protocol
KPI	Key Performance Indicator
LAN	Local Area Network
LB	Location-Based
LOS	Line-Of-Sight
LTE-U	Lone-Term Evolution-Unlicensed
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MD	Mobile Device
NLOS	Non-Line-Of-Sight
OSI	Open Systems Interconnection
PHY	PHYsical layer
PoC	Proof of Concept
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAT	Radio Access Technology
RE	Radio Equipment
RIE	Radio Interface Engine
RLAN	Radio Local Area Network
SDR	Software Defined Radio
SNR	Signal-to-Noise Ratio
SW	Software
UE	User Equipment
VLC	Visible Light Communications
WAS	Wireless Access System
WD	Wireless Device
WE	Wireless Equipment
WiFi®	Wireless Fidelity

4 Eco-System for a Radio Interface Engine (RIE)

4.0 General

The radio interface engine empowers a decision unit to operate in a heterogeneous environment. The unit can be either located at the mobile device or in the network. The decision relies on the eco-system that comprises multiple entities, as such as a context information acquisition entity, context management entity, configuration management entity, flexible modulation entity and others. The radio interface engine enables the efficient acquisition and management of context information and suitable equipment configuration in a heterogeneous radio environment.

4.1 General description and reference to past work

The present document will address the efficient acquisition and management of context information and suitable equipment configuration in a heterogeneous radio environment. In particular, an eco-system within the equipment will be defined in order to achieve this objective. Such an eco-system may comprise entities such as:

- Context Information Acquisition Entity.
- Context Management Entity.
- Configuration Management Entity.
- Flexible Modulation Entity.
- And others.

In ETSI TR 103 062 [i.1] a set of four use cases is described together with actors and information flows for a proposed Software Defined Radio (SDR) Reference Architecture for Mobile Devices (MDs). In [i.2] several use cases are classified with potential requirements for future applications. In [i.3] and [i.8], radio link reliability key performance indicators are described as radio interface engine decision unit for flexible Radio Access Technology (RAT) management as well as flexible modulation entity.

4.2 Capabilities of a Radio Interface Engine

The purpose of the radio interface engine is to provide a defined method to interchange relevant context information to a decision unit. The Radio Interface Engine (RIE) provides a standard interface access to model based data that could represent historical data or relies on typical alternatively characterized scenarios. The predictive decision making relies on context information which serves as input to the RIE. The reliability of the data is improved by the RIE through iterative processing including a combination of multiple sources and KPI based decision making.

Figure 1 shows as an example to illustrate how an iterative process in a dynamic scenario using prior knowledge helps to improve various performance indicators. Assuming a UE moves from network A to network B, the performance of the vertical handover depends on an accurate location estimate. The location estimate itself relies on the chosen waveform, which consequently also defines the throughput in the given scenario. The overall throughput benefits from the current location estimate more than it loses by using a dedicated location waveform. The knowledge that the UE will remain in network A relieves the need on a precise location estimate and therefore a signal waveform can be chosen that is better for the communication throughput of a single link.

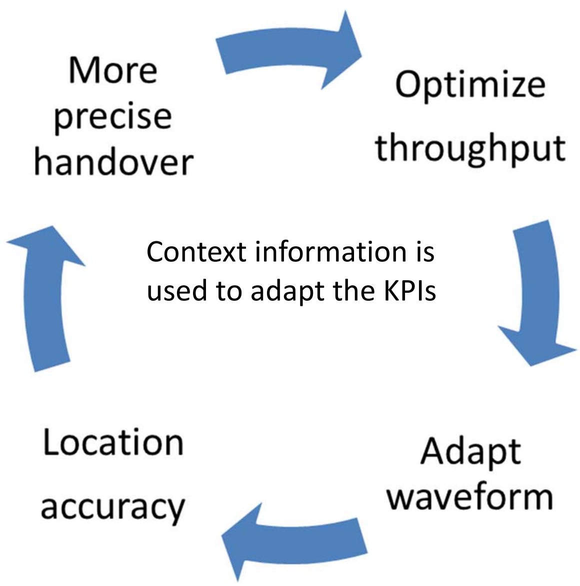

Figure 1: Example of an iterative procedure to improve various KPIs depending on the context information

NOTE: A decision unit can be internal and/or external to the RIE. The overall decision process comprises the internal and external decision units.

5 Key Scenarios

5.1 Overview

In the following key scenarios, identified in clauses 5.2 to 5.6, that will use the RIE are described. For each scenario, the following structure is used:

1) general scenario description;

2) usage example; and

3) role and usefulness of the engine.

The 1st proposed scenario relates to a mobile device and network centric decision making. This contribution is partly based on ETSI TR 103 062 [i.1].

The 2nd proposed scenario is related to user circumstance context information management.

The 3rd scenario considers context information to download and install a different PHY/MAC protocol of wireless devices.

The 4th scenario studies the context to decide where the proper processing unit should be executed.

The 5th scenario relies on the available context information to adapt PHY and MAC to better estimate the position of the wireless devices. All the presented scenarios rely on context information, such as location information. In clause 5.6 the estimated location information as an input will be improved by adapting the wireless configuration and exploiting device-to-device exchanges between MDs themselves.

5.2 Scenario "Optimized Configuration selection in a Heterogeneous Radio Context"

5.2.1 General Scenario Description

A Mobile Device (MD) is able to operate in a heterogeneous wireless framework, typically consisting of Cellular systems, Wireless LAN, Wireless Personal Area Networks, mmWave systems, proprietary communications systems, etc. Some of these systems may be integrated into a common framework or they may be managed independently. Based on its reconfiguration capabilities, the MD is maintaining link(s) to a single RAT or a set of multiple RATs simultaneously (i.e. a data-stream may be optimally split across multiple links), depending on the context in order to optimize the operational conditions (e.g. optimization of power consumption, interference mitigation and carrier aggregation, etc.). The final configuration is typically identified subject to network constraints (e.g. ensuring an overall efficient network configuration) as well as user requirements (e.g. meeting a minimum Quality of Service level at the best possible power consumption, etc.).

The acquisition of context information will be exploited in order to identify the best possible network configuration.

End users: End Users' MDs accessing internet and other similar mobile data services. Additional stakeholders may be considered as appropriate.

5.2.2 Usage example

As illustrated in Figure 2, the acquired context information is exploited in order to identify the best possible working point for a concerned MD, typically taking network and user requirements into account. Depending on the choice of the decision making entity (e.g. Network centric decision making, MD centric decision making, hybrid decision making split between Network and MD), the context information needs to be transported (and accumulated from various sources) to the decision making entity.

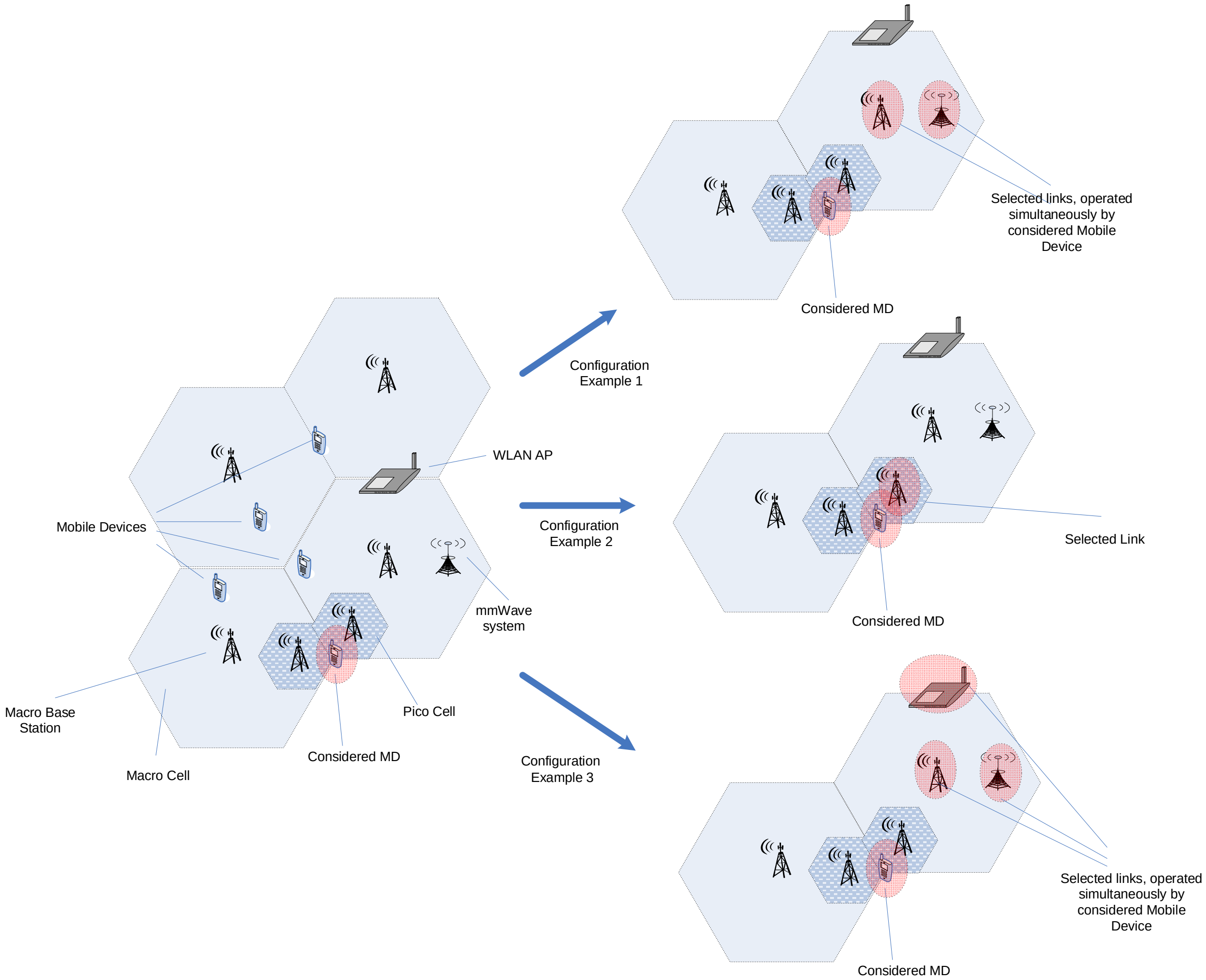

Figure 2: Scenario Illustration "Optimized Configuration selection in a Heterogeneous Radio Context" - the best combination is identified comprising of a single link or multiple links being operated simultaneously

While Figure 2 illustrates the configuration options from a MD perspective, a similar exercise can be performed for the network side. In particular, the most appropriate combination of Base Stations is identified for a target MD with multiple links possibly being operated simultaneously as illustrated in Figure 3. Signalling headers and mixed data and signalling information may be exploited to evaluate associated link reliability metrics (power consumption, QoS, link budget based key performance indicators) in order to make the decision on station selection and on the selection of single or multiple transmission links.

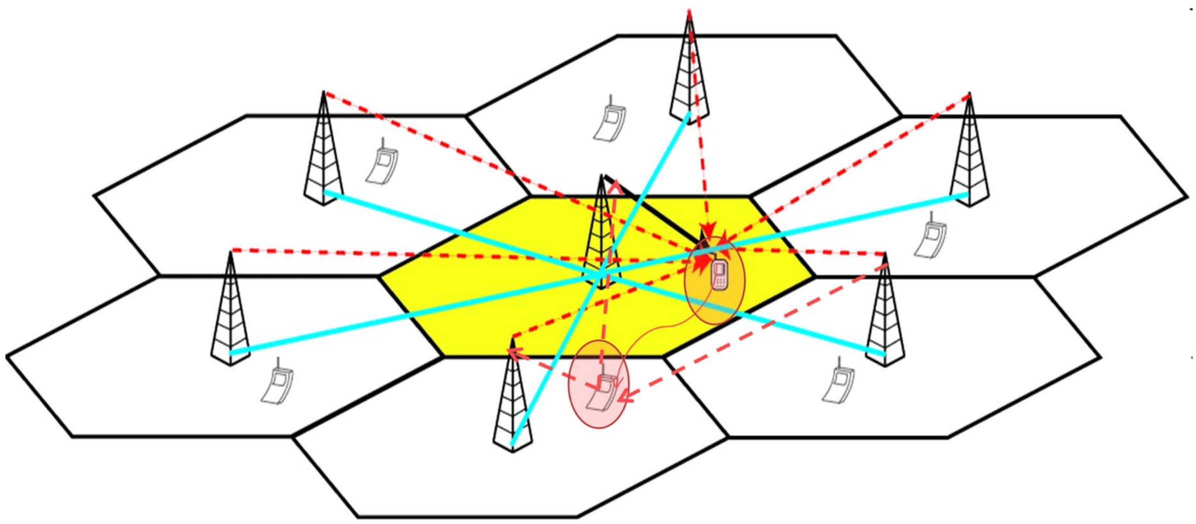

Figure 3: Selection of base station and radio link simultaneously in a time-variant and MD moving configuration

In this scenario, the most appropriate (combination of) base station(s)/access point(s) may be selected for a MD for establishing a link, depending on MD and base station locations and associated radio link reliability based on available transmission interfaces and dedicated link reliability metrics.

When Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) transitions affect the MD in a mobile environment, the access point switching may provide higher link reliability in connection with environment transitions. The selection is combined with transmission link and Modulation-and-Coding-Scheme (MCS) selection. As an example, MCS 16-QAM ¾ and 64-QAM ½ exhibit equivalent information data rate. In NLOS, the 64-QAM ½ is more performant than 16-QAM ¾ due to robust FEC coding rate. During the transitions, the MCS switching involves gains up to 3-4 dB on link budget. In LOS, the 16-QAM ¾ MCS provides better performance, following a lower modulation order compared to 64-QAM. Examples are detailed in [i.3], using a link budget based link reliability metric.

Furthermore, dynamic PHY/MAC processing and link selection may be applied for each RAT: by computing link reliability metrics, the MD may modify transmission link based on dynamic carrier/sub-carrier aggregation and Binary Interleaving Code Modulation process to limit power consumption. Dynamic carrier/sub carrier aggregation may be simply computed using several interleaving patterns to aggregate carriers in a logical channel.

5.2.3 Role and Usefulness of the Engine

The Radio Interface Engine is supporting the upper reconfiguration framework. In particular, the following features are provided by the Radio Interface Engine in a unified way:

- Standardized acquisition of context information, depending on the available sensors, such as location determination, characterization of radio links, interference environment, etc.
- Standardization distribution (and possibly aggregation) of context information provided by one (or multiple) sources. Provide (processed) context information to decision making entity.
- Link reliability metric definition.
- Procedure to compute link reliability metrics and station/MD location using available information to the MD and base station.
- HW accelerators for multiple link transmission solutions composed of different processing components.

5.3 Scenario "User Circumstance Context Information Management"

5.3.1 General Scenario Description

Wireless Equipment, such as mobile devices, vehicle-to-X communication equipment, Internet-of-Things Devices, etc. is typically used in various circumstances which are either unique - e.g. a User is for a one-time visit in a foreign city - or which may occur again (in cycles) - e.g. a User is driving from his home to work, takes kids to schools, etc. This scenario addresses the case, in which an equipment user finds itself repeatedly in similar User Circumstances. In such a case, it is proposed to store (averaged) observation of the Context Information, e.g. availability of specific RATs, link quality metrics, the type of applications being used, etc. in a database. When the concerned User is identified to be in similar User Circumstances again, the historic information is exploited - typically in combination with instantaneous context measurements - in order to implement predictive decision making. I.e. future changes in Key Performance Indicators (KPIs) are anticipated and corresponding configuration changes are implemented well in advance, e.g. in order to avoid call drops occurring repeatedly in a given area or similar.

End users: End users' wireless equipment accessing internet and other similar mobile data services. Additional stakeholders may be considered as appropriate.

5.3.2 Usage example

As illustrated in Figure 4, the acquired context information is exploited in order to identify the best possible working point for a concerned Wireless Equipment. For this purpose a combination of instantaneous observations together with historical (averaged) data is used in order to enable predictive decision making. Depending on the choice of the decision making entity (e.g. Network centric decision making, Wireless Equipment centric decision making, hybrid decision making split between Network and Wireless Equipment), the context information needs to be transported (and accumulated from various sources) to the decision making entity.

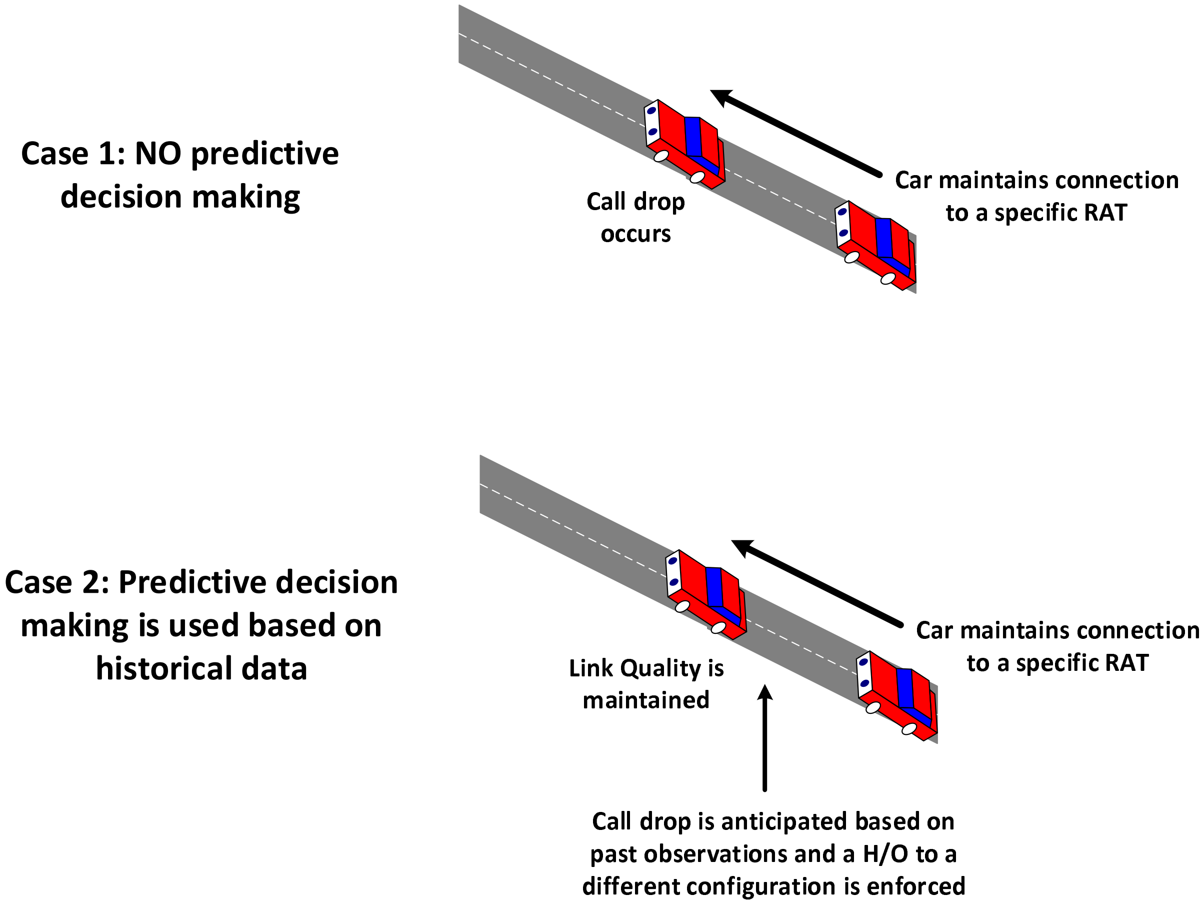

Figure 4: Scenario Illustration "User Circumstance Context Information Management" - a call drop is avoided by exploiting past observations

5.3.3 Role and Usefulness of the Engine

The Radio Interface Engine, typically within a given Wireless Equipment, is supporting the upper reconfiguration framework. In particular, the following features are provided by the Radio Interface Engine in a unified way:

- Standardized acquisition of instantaneous context information, depending on the available sensors, such as location determination, characterization of radio links, interference environment, etc.
- Transfer of instantaneous context information to processing entity for:
  - i) deriving historical (averaged) database entries; and
  - ii) deriving a machine readable representation of the User Circumstances.
- Standardized access to historical (averaged) information for supporting predictive decision making.

5.4 Scenario "Protocol download and installation in Wireless Equipment depending on the context"

5.4.1 General Scenario Description

Wireless Equipment (WE), such as mobile devices, vehicle-to-X communication equipment, Internet-of-Things Devices, etc., is able to operate in a heterogeneous wireless framework, typically consisting of Cellular systems, Wireless LAN, Wireless Personal Area Networks, mmWave systems, proprietary communications systems, etc. Some of these systems may be integrated into a common framework (e.g. integration of WiFi® and cellular technologies) or they may be managed independently.

Based on its reconfiguration capabilities, new software components are installed in the WE replacing protocols on the appropriate OSI layers (e.g. PHY, MAC, etc.) on the context (e.g. Context Information) in order to optimize the operational conditions (e.g. interference mitigation). The protocol is typically identified subject to network constraints (e.g. ensuring an overall efficient network configuration) as well as user requirements (e.g. meeting a minimum Quality of Service level at the best possible power consumption, etc.).

The acquisition of context information will be exploited in order to identify the best possible communications protocol [i.4] and [i.5].

End users: End users' wireless equipment accessing internet and other similar mobile data services. Additional stakeholders may be considered as appropriate.

5.4.2 Usage example

As illustrated in Figure 5, the acquired context information is exploited in order to identify the best possible communication PHY/MAC protocol for a concerned WE, typically taking network and user requirements into account. The chosen PHY/MAC protocol is installed in the WE. Depending on the choice of the decision making entity (e.g. Network centric decision making, WE centric decision making, hybrid decision making split between Network and WE), the context information needs to be transported (and accumulated from various sources) to the decision making entity.

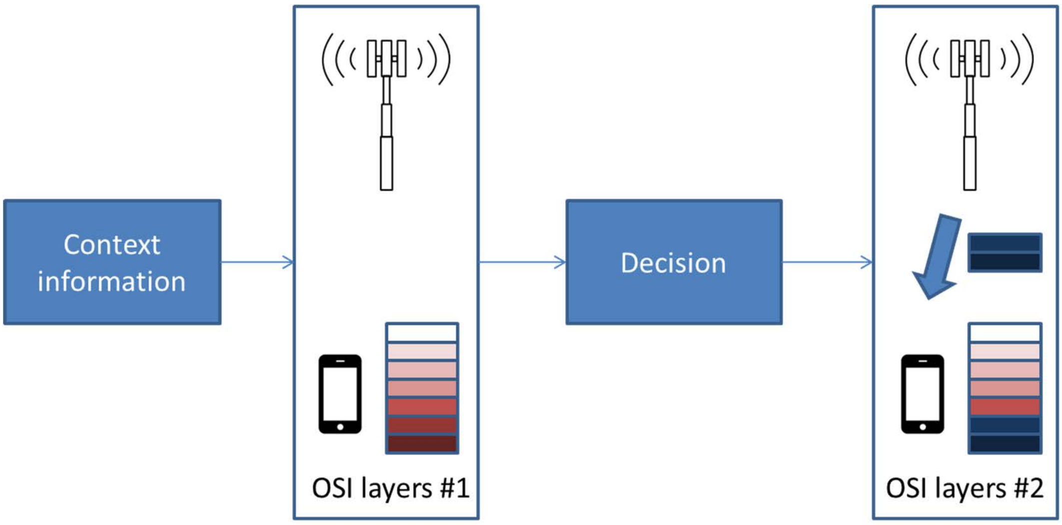

Figure 5: Scenario Illustration "Protocol download and installation in Wireless Equipment depending on the context" - a wireless equipment downloads and installs the two lower OSI layers (PHY/MAC) based on a decision taken according to the available context

EXAMPLE: MAC protocol download in the presence of structured interference.

A given WE, e.g. a WiFi® node, is using a certain MAC protocol, which provides a certain QoS under the current environment conditions. However, at a certain point in time, an external structured quasi-periodic and impulsive interference appears, e.g. due to an LTE-U transmission in the same band, which decreases the achievable QoS. Since the interference is impulsive and quasi-periodic, it can be easily predicted and, if known, it would be trivially avoided by MAC protocol operation. Rather than a priori designing a MAC protocol so as to integrate support for avoidance of such structured interference, which would create a significant overhead in situations where there is no interference, the WiFi® node can use the context information to detect if, in the current environment, there is an active interference and which is its pattern, and then download and switch to a MAC protocol specifically designed for avoiding that specific pattern.

5.4.3 Potential supporting functionalities of a Radio Interface Engine

The Radio Interface Engine, typically within a given WE, is supporting the upper reconfiguration framework. In particular, the following features are provided by the Radio Interface Engine in a unified way:

- Standardized acquisition of context information, depending on the available sensors, such as location determination, characterization of radio links, interference environment, etc.
- Standardization distribution (and possibly aggregation) of context information provided by one (or multiple) sources. Provide (processed) context information to decision making entity.

5.5 Scenario "Processing device selection for execution of protocols in a Wireless Equipment depending on the context"

5.5.1 General Scenario Description

Wireless Equipment (WE), such as mobile devices, vehicle-to-X communication equipment, Internet-of-Things Devices, etc., is able to operate in a heterogeneous wireless framework, typically consisting of Cellular systems, Wireless LAN, Wireless Personal Area Networks, mmWave systems, proprietary communications systems, etc. Some of these systems may be integrated into a common framework (e.g. integration of WiFi® and cellular technologies) or they may be managed independently.

Based on its reconfiguration capabilities, the execution of some components of the appropriate OSI layers (e.g. channel estimation in PHY) is moved from a certain processing device (e.g. FPGA) to another one (e.g. GPP) depending on the (e.g. Context Information) in order to optimize the operational conditions (e.g. energy consumption). The target processing device is typically identified subject to network constraints (e.g. ensuring an overall efficient network configuration) as well as user requirements (e.g. meeting a minimum Quality of Service level, etc.).

The acquisition of context information will be exploited in order to identify the best possible target processing device.

End users: End users' wireless equipment accessing internet and other similar mobile data services. Additional stakeholders may be considered as appropriate.

As illustrated in Figure 6, the acquired context information is exploited in order to identify the best possible execution device for the components of the appropriate communications protocol of a concerned WE, typically taking network and user requirements into account. Depending on the choice of the decision making entity (e.g. Network centric decision making, WE centric decision making, hybrid decision making split between Network and WE), the context information needs to be transported (and accumulated from various sources) to the decision making entity.

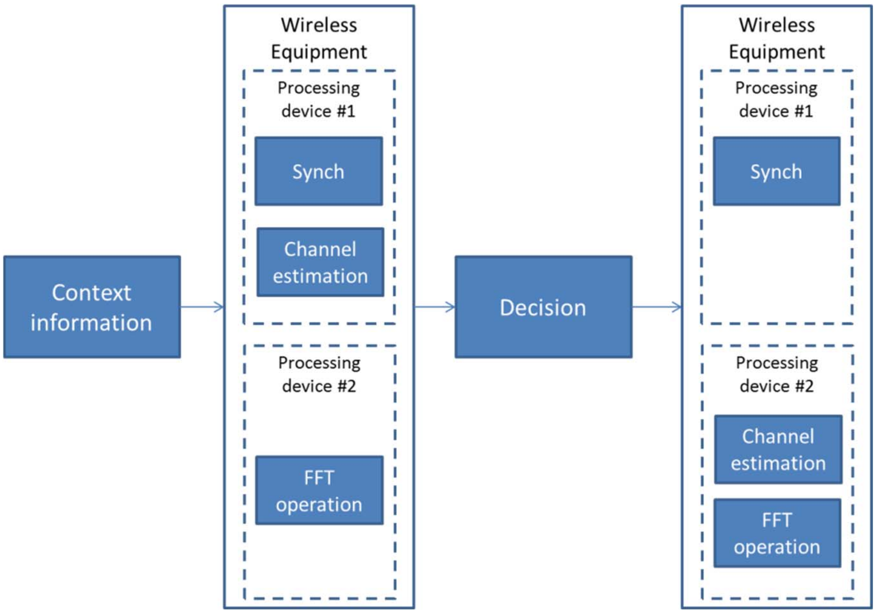

Figure 6: Scenario Illustration "Processing device selection for execution of protocols in Wireless Equipment depending on the context" - a wireless equipment changes the processing device where the channel estimation function is executed based on a decision taken according to the available context

5.5.2 Usage example: Energy aware selection of processing device

A given WE, e.g. a cellular base station, may be operating under different load conditions depending on environmental conditions [i.6]. For example, if the base station is serving an outdoor park, the cell load will be directly related to the weather conditions. For situations where the load is high (good weather conditions) and many users need to be served, the most time consuming operations of the protocol stack (e.g. PHY processing) are executed in high performance devices (like FPGAs). In the situation where the weather is likely to change, as predicted by humidity, temperature, and pressure sensors, which provide the context information, the cell load will tend to decrease rapidly. Thus, under the new circumstance of low cell load, the decision making entity selects a less performant less energy consuming processing device (e.g. GPP) to perform the PHY processing, with the purpose of serving the reduced number of users at lower energy consumption and power radiation with a QoS target.

5.5.3 Potential supporting functionalities of a Radio Interface Engine

The Radio Interface Engine, typically within a given WE, is supporting the upper reconfiguration framework. In particular, the following features are provided by the Radio Interface Engine in a unified way:

- Standardized acquisition of context information, depending on the available sensors, such as location determination, characterization of radio links, energy consumption metrics, etc.

- Standardization distribution (and possibly aggregation) of context information provided by one (or multiple) sources. Provide (processed) context information to decision making entity.

5.6 Scenario "Improving Location Information"

5.6.1 General Scenario Description

In this scenario the Wireless Device (WD) is in range of multiple other devices to support the determination of the location by different means. The radio behaviour is reconfigured and additional sensor information is gathered to fulfil the requirements for applications that need details about the whereabouts and the route of the Wireless Device (WD).

The applications that require precise location information are for example communication improvements such as improved synchronization, handover between different networks, or higher layer location based services. The dynamic details can be enriched with mobility information of the WD from non-radio sensors as well as with context information, such as detailed 3D-maps of static or dynamic objects in the surroundings.

The requirements are regularly assessed and the location performance itself is evaluated. Depending on both criteria the following options are foreseen:

- Option 1) adapts the communication signal to improve the ranging estimation by e.g. changing the waveform [i.7], the bandwidth or the signal power.
- Option 2) requests information from surrounding WDs about their available context information such as other radios, or environmental information.
- Option 3) requests location relevant information such as location and its reliability information of the location estimation to determine the own location according to its performance requirements.

Figure 7 sets up a scenario of multiple mobile WDs that have peer-to-peer links with one WD (MT_x) that has no direct connectivity to the core network. Through these wireless links themselves or by exchanging relevant information (own information or from the network through the base stations) the location performance is improved. Location based techniques may exploit channel state information resulting from the multipath distribution of the channel impulse response estimation of the propagation channel between two reference transmitter and receiver to estimate the location of the WD.

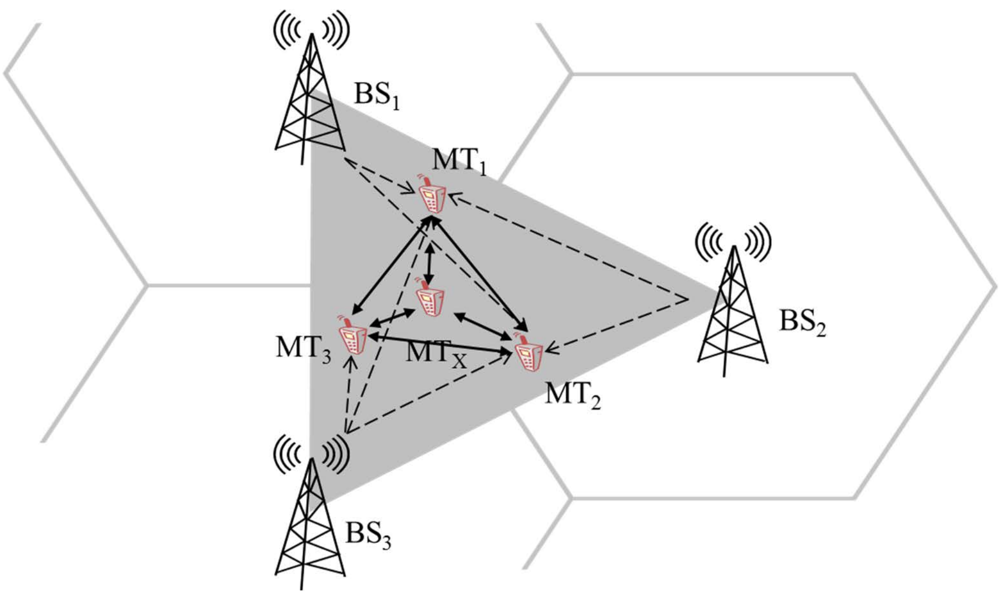

Figure 7

The location information delivers details about the whereabouts and future locations of the wireless device.

The main concept is to abstract the resources of the wireless device regardless of the specific internal architecture, by exposing simple programming interfaces able to read the state of the resources and to apply the selected configuration, according to decisions taken by a local SW agent interacting with controller that either adapts resources or initiates the exchange of information. A graphical representation of this concept can be found in Figure 8.

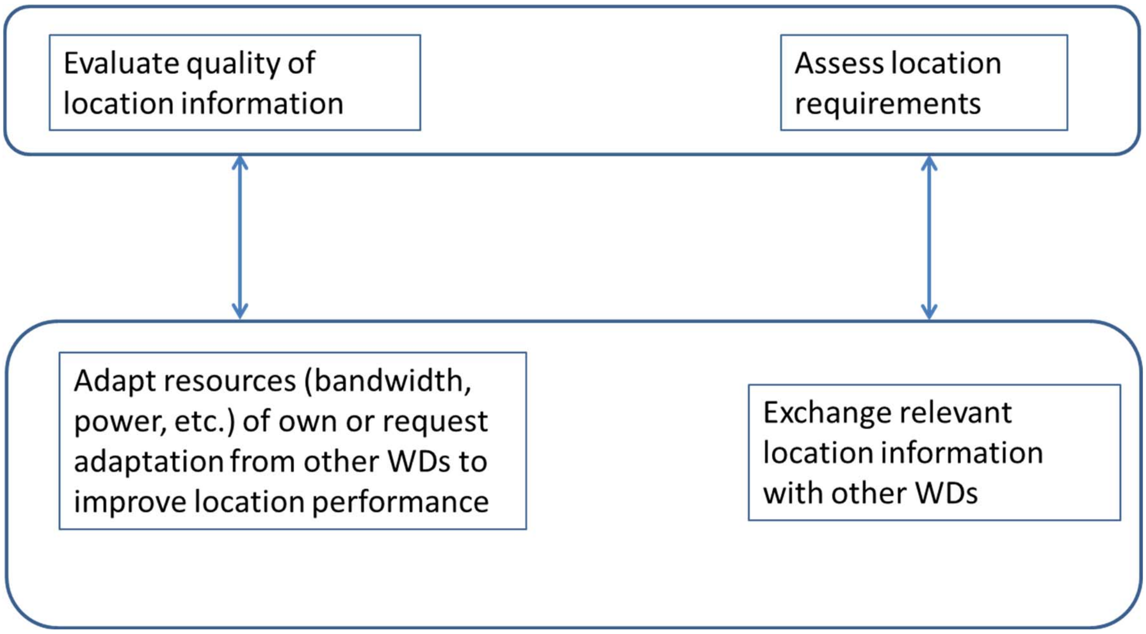

Figure 8

To this purpose, different types of resources are considered:

i) multiple programmable radio interfaces, with heterogeneous technologies (e.g. typically consisting of Cellular systems, Wireless LAN, Wireless Personal Area Networks, VLC, plus out band or inband device-to-device), exposing a common set of APIs for configuring the physical channels and the medium access rules;

ii) sensors, such as those commonly available in commodity smartphones, including barometers, gyroscopes, cameras, accelerometers, etc., as well as specific other sensors that are also available in base stations (temperature, humidity, pressure, etc.) available in monitoring or metering devices.

This scenario considers the following relevant operation modes, in which location information of higher precision is required and accomplished:

i) selecting the RAT technology to connect to according to the geometrical constellation of all entities, the link quality or activating new resources;

ii) configuration of device medium access and PHY rules.

The stakeholders in this scenario would be:

- End users: mobile devices accessing internet and other similar mobile data services.

A single or multiple Network operators: operate(s) and maintain(s) the required infrastructure; may operate other networks in other frequency bands.

5.6.2 Usage example

In the following, an example is provided:

1) To adapt the RAT technology like the waveform to improve the ranging quality between radio entities to improve the location information of the radio entity itself. This topic is especially relevant for:

   i) dynamic resource allocations for estimating the time-varying and location-dependent interference; and

   ii) D2D communication, as detecting a potential D2D partner nearby.

2) Multiple links from several RATs exist, and some of them have Line-of-sight and some have Non-line-of-sight conditions to the receiver. The software agent adapts its resources according to the decision unit that evaluates the condition of each link. Such resources can be e.g. adaptive transmit power, available bandwidth, or differently structured pilot signals. The benefit is improved estimated location information based on the supported RATs.

5.6.3 Role and Usefulness of the Engine

In this scenario the role of the engine is to select and adapt the RAT technology, configure its PHY/MAC rules and perform dynamic resource allocations to improve the available estimated location and environment information. The Engine would therefore gather improved location and environment information to further improve the operational radio communication scope of the engine, such as throughput, delay and other application-level figures, as well as low-level channel figures, such as collision probability, channel occupancy, etc. This is an important ingredient to all prior scenarios in clauses 5.2 to 5.5.

6 Additional Use Cases for location-based spectrum sharing

6.1 Introduction

The change of the reconfigurable radio ecosystem restated from the evolution of the European legal system and its regulatory application, and by the evolution of practical application of technology on a local scale.

Evolution of technology and radio networks deployments are covered by the examples of use cases in geolocation capability.

The spread of technology, and its penetration in more and more locations and all corners of modern life are natural factors in favour of increased efficiency of spectrum sharing. Specific locations are particularly in demand for spectrum usage by multiple networked technologies and therefore efficient methods for spectrum sharing are needed.

Spectrum sharing ecosystems are defined from several competing perspectives of stakeholders each playing a role in the ecosystem:

- protection of existing/incumbent services, often associated with existing infrastructure services and ensuring the stability of certain functionality;
- regulating the use of spectrum with a view to encourage efficient use of spectrum and a stable evolution through innovative means, without harm of existing network functionality;
- penetration of new technology that responds better to the needs of contemporary markets and the creation of new functionality.

Several common elements may be detected in these perspectives:

- functionality is preserved and enhanced in order to satisfy increased demand of spectrum usage;
- networks are deployed and have specific performance relative to each other and to a defined location.

Standardization efforts for defining the best method of testing for ensuring unencumbered functionality of incumbents and satisfying increased usage of the spectrum outside of the protected location are based on parameters derived from the examination of the elements described above.

6.2 Geolocation capability on WAS/RLAN equipment for spectrum innovative sharing solutions

6.2.1 Geolocation capability for spectrum sharing use cases

Several examples of use cases for sharing spectrum in unlicensed regime bands are given in the present clause. Unlicensed devices could have access to the spectrum in defined geographic zones through the comparison of their geolocation data and the defined protection zones or defined country geographic zone.

The device may set up by itself (automatically without the intervention of the final user) taking into account the stated rules for the access to the spectrum in determined geographic zone. The protection zones are defined through the calculations made taking into account technical parameters stated in technical studies. Technical parameters depend on the incumbents in the shared band.

The examples deal with WAS/RLAN applications working in unlicensed regime bands. The proposed use cases describe shared bands between WAS/RLAN and primary incumbents such as radiolocation, fixed services and some technologies such as Road Tolling. WAS/RLAN devices could work in indoor (inside buildings or cars) or in outdoor installations. The accuracy of the geolocation data obtained by the WAS/RLAN device is key to make sure that the algorithm of decision will allow the protection of incumbents sharing the spectrum band.

6.2.2 Static access to the spectrum depending on defined protection zones

WAS/RLAN devices sharing spectrum with some incumbents or application may avoid their operation in zones where these incumbents operate. In this scenario WAS/RLAN devices are static in terms of geolocation, it may be in a fixed outdoor or indoor installation. The protection zones depend on the technical parameters and calculations set out through technical studies. A database may contain the data with the protection zones and provide this information to WAS/RLAN devices. At this stage it is not clear whether the database will treat directly the WAS/RLAN geolocation and provide the decision about the allowance or not to use the spectrum, or the decision will be made by the WAS/RLAN device itself taking into account the information sent by the database.

6.2.3 WAS/RLAN sharing with Road Tolling application (5,8 GHz band)

ECC Report 244 [i.9] suggests an approach based on the use of a geolocation database: The road tolling roadside units are generally fixed with a determined location. Information can be stored in a database and mechanisms may be developed so that this information may be used by RLAN to avoid interference.

The usage of a geolocation database would use a central registry. This central registry may hold an updated inventory of all databases in Europe which holds information on road sections and the appropriate 5,8 GHz road-tolling implementations. The geolocation database may hold actual information from static and, due to construction sites, temporal tolling installations. From a technical point of view, this includes any 5,8 GHz road-tolling application that requires protection, including information about 5,8 GHz mobile enforcement installations, when these are available or as they are updated.

The implementation of such a platform, its access, its maintenance may be addressed. In addition, the role and responsibilities or the stakeholders would have to be clearly defined.

The RLAN equipment on the other hand may have access to the inventory of 5,8 GHz implementations according to its actual position by retrieving information from the geolocation data base. This will allow the RLAN equipment to start mitigation procedures if it comes close to a 5,8 GHz road-tolling implementation.

6.2.4 Scenario A1: Indoor RLAN

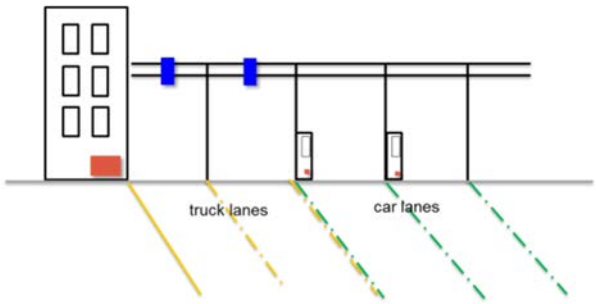

Figure 9: Scenario A1 - Indoor RLAN and road tolling

The 5 GHz RLAN device is situated close to the road tolling system. Figure 9 shows an example with a multilane road toll. The 5 GHz RLAN transmitter appears in red and the tolling road-side units are shown in blue. In this scenario it is assumed that the 5 GHz RLAN device, or access point is close to the road tolling communication zone, but situated inside a building. There are also other possible scenarios the multilane road toll depicted here is just an example. Other examples could be tolling points within city centres, access point to parking lots, etc. Buildings close to the streets not being owned or controlled by the tolling operator are considered. In this building, RLAN devices could be operated without any influence by the tolling operator, as per ECC Report 244 [i.9].

6.2.5 Scenario A2: Dynamic access to the spectrum depending on defined protection zones

The scenario for dynamic access to the spectrum depending on defined protection zones is similar to the scenario described above. The difference is that WAS/RLAN devices are mobile and in an inside-vehicle installation. It means that the device may check out its geolocation and ask information to the database about the protection zones more frequently than in the static case.

EXAMPLE: WAS/RLAN sharing with Road Tolling application (5,8 GHz band) - ECC Report 244 [i.9].

NOTE: Use of geolocation database approach: The road tolling roadside units are generally fixed with a determined location. Information can be stored in a database and mechanisms may be developed so that this information may be used by RLAN to avoid interference.

6.2.6 Scenario A3: Outdoor RLAN

This is the same as scenario A1 except that the RLAN device is situated outside of a building.

6.2.7 Scenario B: RLAN on-board a vehicle

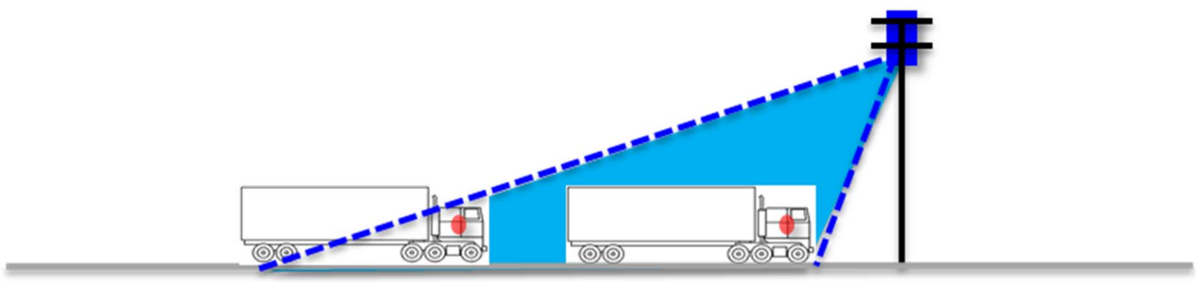

Figure 10: Scenario B - Outdoor RLAN and road tolling

Here the 5 GHz RLAN transmitters are found inside the vehicle. If the RLAN device is transmitting within the road tolling communication zone, its transmission would radiate through the vehicle window interfering directly with uplink communications to the tolling road side receiver antenna. In the case of a cabriolet or a motor cycle there is no wind screen, which normally reduce transmit power by 3 dB as per ECC Report 244 [i.9].

6.2.8 Country Determination Capability

Country determination capability is a (software) functionality implemented on the device which aim is to decide how the device is allowed or not to use the spectrum depending on the current country location of the device. In order to make this decision the device may check its current geolocation, have access to a table that contains the relation between the country and the stated rules to use the band (regulatory table provided by an authority designated).

The aim of this functionality is to provide a mechanism to set up automatically the device to have access to the spectrum without the intervention of final users. This capability of the device could be seen as a mitigation technique for sharing spectrum in environments where regulatory harmonisation over CEPT countries is not possible. It is expected that this functionality will allow the economy of scale on mass market devices particularly when harmonisation at CEPT level is not possible.

For example for this scenario, WAS/RLAN sharing is considered with Radiolocation service particularly with Fast Frequency Hopping radars (5,8 GHz band).

WAS/RLAN and radiolocation service share already two other frequency bands in the 5 GHz band, where DFS is used as mitigation technique to protect Radiolocation service. In the particular case of 5,8 GHz band, there is a specific kind of radars that use Fast Frequency Hopping modulation, these radars are operating in some CEPT countries. Technical studies demonstrated that DFS is not effective as mitigation technique for the sharing between WAS/RLAN and Fast Frequency Hopping radars. Therefore, Country Determination Capability (CDC) is proposed as an innovative solution that could allow the use of 5,8 GHz band in some countries and exclude its use in countries where Fast Frequency Hopping radars are operating.

WAS/RLAN devices are envisaged to operate in indoor environments in 5,8 GHz band.

Desirable characteristics of the geolocation mechanism:

- Good precision on the device geolocation.
- Information on geolocation is verifiable through many ways (e.g. GNSS, IP address, other) to have certainty.
- The geolocation is made automatically by the device itself at the moment of switching on.

6.3 Evolution of regulatory and legal framework

The evolution of the legal framework and its regulatory application is seen in the two EC Decisions mentioned here:

- Commission Implementing Decision (EU) 2018/1538 of 11 October 2018 on the harmonisation of radio spectrum for use by short-range devices within the 874-876 and 915-921 MHz frequency bands [i.10].
- Commission Implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC updating harmonised technical conditions in the area of radio spectrum use for short-range devices (notified under document C(2019) 5660) [i.11].

The evolution of the legal framework and its regulatory application is shown in the Commission Implementing Decision (EU) 2018/1538 of 11 October 2018 on the harmonisation of radio spectrum for use by short-range devices within the 874-876 and 915-921 MHz frequency bands.

Under this act, Wideband data transmission systems may use the frequency band 917,4 MHz to 919,4 MHz, if they comply with a number of requirements and if the Member State does not restrict the use of the band due to concerns of interference to existing services. This type restrictions of the allowed use are described in Article 3, paragraph 2 of the Decision 2018/1538 as follows in the quote below:

"*Member States may take appropriate measures to protect existing use in the 874-876 MHz and 915-921 MHz spectrum to the extent necessary and where no alternative protective solution may be found through coordination of the various types of uses in those bands. This may include the imposition of additional technical, geographic or operational requirements for the use of the band while complying with the harmonised technical conditions for spectrum access set out in the Annex*".

The Radio Equipment Directive (RED) creates the premise in the legal framework for developing the standard for location-based spectrum usage. For example, in the Radio Equipment Directive, in Chapter II, under Obligations of Manufacturers, in the text of Article 10 paragraph 10, the requirements are as follows:

"*In cases of restrictions on putting into service or of requirements for authorization of use, information available on the packaging shall allow the identification of the Member States or the geographical area within a Member State where restrictions on putting into service or requirements for authorization of use exist. Such information shall be completed in the instructions accompanying the radio equipment. The Commission may adopt implementing acts specifying how to present that information*".

6.4 Consideration of possible system requirements for location-based spectrum sharing

An example of a location-based enabling of RE set of requirements to be implemented in the design may be as follows.

The Location-Based compliant (LB) RE is designed so that the RE is by default placed in receive only mode for a fixed period of time:

- upon power-up; or
- after commissioning; or
- after reconfiguration; or
- if the policy requires it, at fixed time intervals.

The following is assumed:

- This fixed period is greater than the time normally necessary for determining its location, i.e. the determination period.
- The LB RE does not enable transmission mode if the location of the RE cannot be determined.
- The LB RE does not determine its location if two geographically relevant coordinates cannot be determined within its determination period.
- The LB RE does not determine its location if the determination period cannot be determined using reliable and accurate time-stamps.
- The LB RE does not determine its location if the accuracy of the determination is not reliably verified and is not compliant with the policy rules.
- The LB RE does not determine its location if it cannot verify that its policy rules are updated and valid.

7 Conclusion

In the present document several scenarios are presented to improve communication KPIs, such as throughput, energy consumption and reliability of the wireless link as well as the location accuracy. The RIE that is responsible to execute the appropriate action distributes or collects the required context information. Not all KPIs are correlated with each other, and therefore the RIE could also iteratively initiate action based on additional context information to improve an uncorrelated KPI. The resulting KPI could then contain enriched or improved context information to further improve KPIs. For example context information comprises out of location information, the characterization of the wireless link, and the interference reception. In scenario 5.6 the RIE is used to improve the quality of context information, which is the location information, and therefore, all subsequent metrics that are location dependent are noted with higher reliability in conjunction with the estimate of the location.

The next step following these outlined scenario descriptions will include system requirements, the definition of the system architecture and the description of the defined interface of the engine and the required methods to transfer the required context information either instantaneously, or relying on cached historical data or model based data sets, i.e. by a dedicated distribution.

History

Document history		
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