ARTIFICIAL INTELLIGENCE AIDED D-BAND NETWORK FOR 5G LONG TERM EVOLUTION

With the aspiration to transform the current (5G) wireless thinking from focusing on "local" network improvements (e.g. isolating the radio access level or the resources management level etc.), to realizing a longer term vision of pervasive mobile virtual services, through a network managing computing and connectivity functions in an integrated way, ARIADNE envisions to bring together a novel high frequency advanced radio architecture and an Artificial Intelligence (AI) network processing and management approach in a unified system beyond 5G concept.

The vision of ARIADNE is to investigate, theoretically analyze, design, develop, and showcase in a proof of concept demonstrator, an innovative wireless communications concept addressing networks beyond 5G, in which ultra-high spectral efficient and reliable communications in the bandwidth-rich D-band can be dynamically established and reconfigured by Machine Learning (ML)-based design and intelligent network management, in both “Line of Sight” (LOS) and “Non-Line of Sight” (NLOS) environments (Figure 1).

Targeting ultra-reliable and scalable connectivity of extremely high data rates in the 100 Gbps regime at almost ‘zero-latency’, ARIADNE proposes to exploit frequencies between 110-170GHz for access and backhaul links, taking advantage of breakthrough novel technology concepts, namely, the development of broadband and spectrally highly efficient RF-frontends in the D-band, the employment of metasurfaces to cope with obstructed connectivity scenarios and the design of ML-based access protocols, resource and network management techniques. In order to realize this vision, a *novel system model* will be devised, including channel modelling, waveforms, beamforming and multiple-access schemes design and development tailored to the particularities of the D-band regime, *a novel Communication Theory framework beyond Shannon* will be proposed and a *novel (ML-based) network optimization approach* will be formulated.

ARIADNE System Concept

Sustaining a flexible and ubiquitously available 100 Gbps network for backhaul and access in systems beyond 5G will require the exploitation of higher frequency bands, the adoption of novel hardware technologies and advanced materials and the rethinking of Communication Theory framework and traditional design principles and architectures. In this way, in the beyond 5G era, the conventional system concept of a 5G network as a universal resources (physical and virtual) manager will be transformed into the system concept of a fully adaptive (to environmental characteristics, volatility and user requirements), *power-efficient distributed computer and highly reliable connectivity provider.*

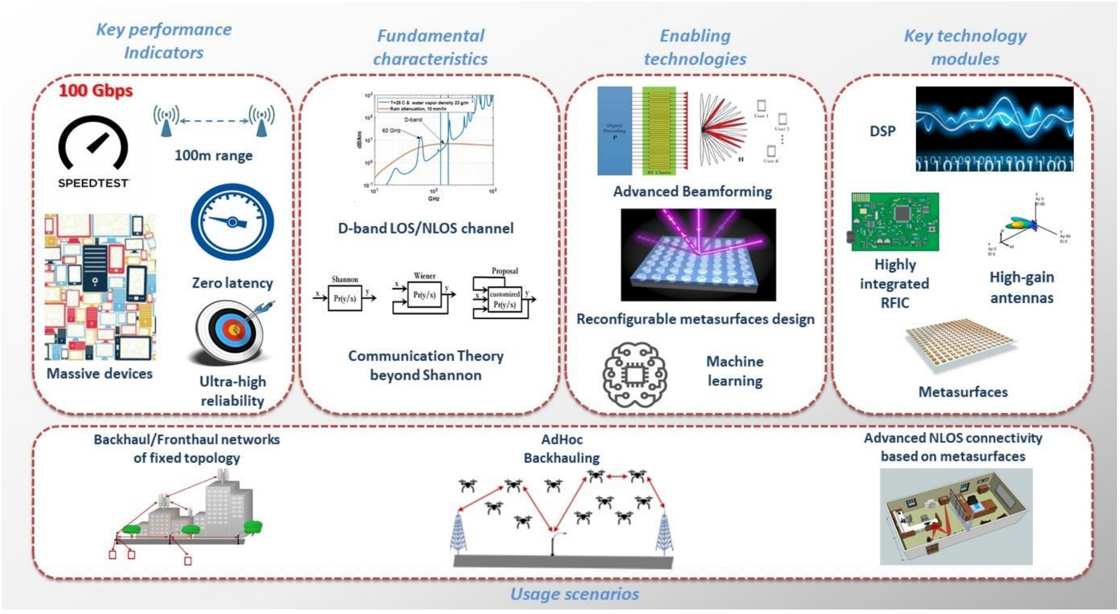


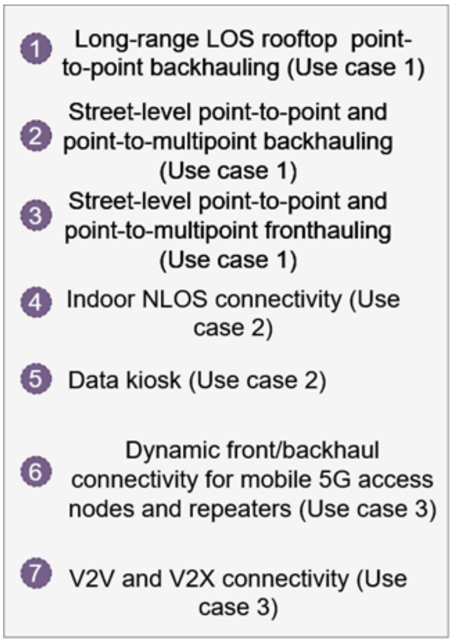
Figure 1 - ARIADNE system concept for networks beyond 5G

Bringing to fruition the notion of AI-aided D-band wireless beyond 5G networks entails the challenges of devising a flexible and powerful ML-based wireless network optimization framework, introducing novel propagation and channel modelling principles and a revolutionary communication theory approach and developing – in a modular fashion - cutting-edge technology components. These include beamforming antenna arrays, metasurface-based intelligent materials, RF-frontends, baseband processing, medium access control protocols, ML-based resources and network management, as well as devising a suitable performance evaluation framework defined by the appropriate critical use cases and relevant performance metrics. Most importantly, ARIADNE will identify, assess and address the critical technology gaps and invent, optimize and demonstrate the appropriate enablers, expected to catalyze the road to beyond 5G. In particular, the ARIADNE approach will be established, developed and evaluated based on *three pillars*:

- **PILLAR I: *D-band* for 100 Gbit/s reliable wireless connectivity, by means of advanced, power-efficient transceiver design,** in order to substantially improve radio spectrum usage by introducing novel strategies for coverage/service extension, supporting of novel use cases, and exploiting today's unexplored spectrum.
- **PILLAR II: *Communications beyond the Shannon paradigm*, by means of metasurfaces for NLOS/obstructed LOS connectivity**, in order to guarantee connectivity reliability, by making the environment itself reconfigurable. It will thus become possible to make the most out of the ultra-high bandwidth resources made available by the D-band and, at the same time, overcome impairments associated with propagation characteristics, usage scenario topology, energy, and complexity limitations.
- **PILLAR III: *Artificial Intelligence* based wireless system concept**, **by means of ML approaches** to optimize the architecture, the signal and data processing and all network management functions, in order to transform networks beyond 5G to intelligent platforms integrating connectivity and computing, thus opening new service models to telecom/ISP providers.

These three ARIADNE pillars represent the main building blocks of the ARIADNE network architecture, which are jointly and optimally combined to successfully address the following 7 major Key Performance indicators (**KPIs**):

- Aggregate **throughput** of wireless access for any traffic load/pattern (*100 Gbps*)
- **E2E throughput** in all relevant usage scenarios, backhaul/fronthaul, ad hoc backhaul, NLOS/obstructed (*100 Gbps*)
- E2E **latency** minimization (*'zero' latency*)
- **Coverage** of the D-band link (*100 m outdoors*)
- Connectivity **Reliability** for massive number of nodes (*'always' available*)
- **Energy efficiency** (energy consumption reduction by 10x compared to 5G)
- **Complexity reduction** (10x compared to 5G)



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Use Case 1: Outdoor backhaul/fronthaul networks of fixed topology

This is one of the most imminent applications of the D-band. More specifically, current wireless backhaul/fronthaul networks have been designed to accommodate the traffic corresponding to sub-6 GHz mobile access networks, such as LTE networks. The vast majority of bands serving that purpose lie in the 6-90 GHz range, which is adequate to meet the current demands.

Due to the forecasted exponential data rate increase, mobile access networks in the forthcoming 5G and beyond networks are going to emigrate towards the lower end mmWave spectrum that corresponds to the 30-90 GHz range and offer a substantially higher bandwidth compared to their sub-6 GHz counterparts. Owing to such a migration, next-generation wireless backhaul/fronthaul networks will need to migrate towards the beyond 100 GHz spectrum so to accommodate, through the higher offered bandwidth, the ever-increasing data-rate demands of mobile users. Hence, D-band comes as a solution to the expected capacity bottleneck of current outdoor backhaul/fronthaul networks.

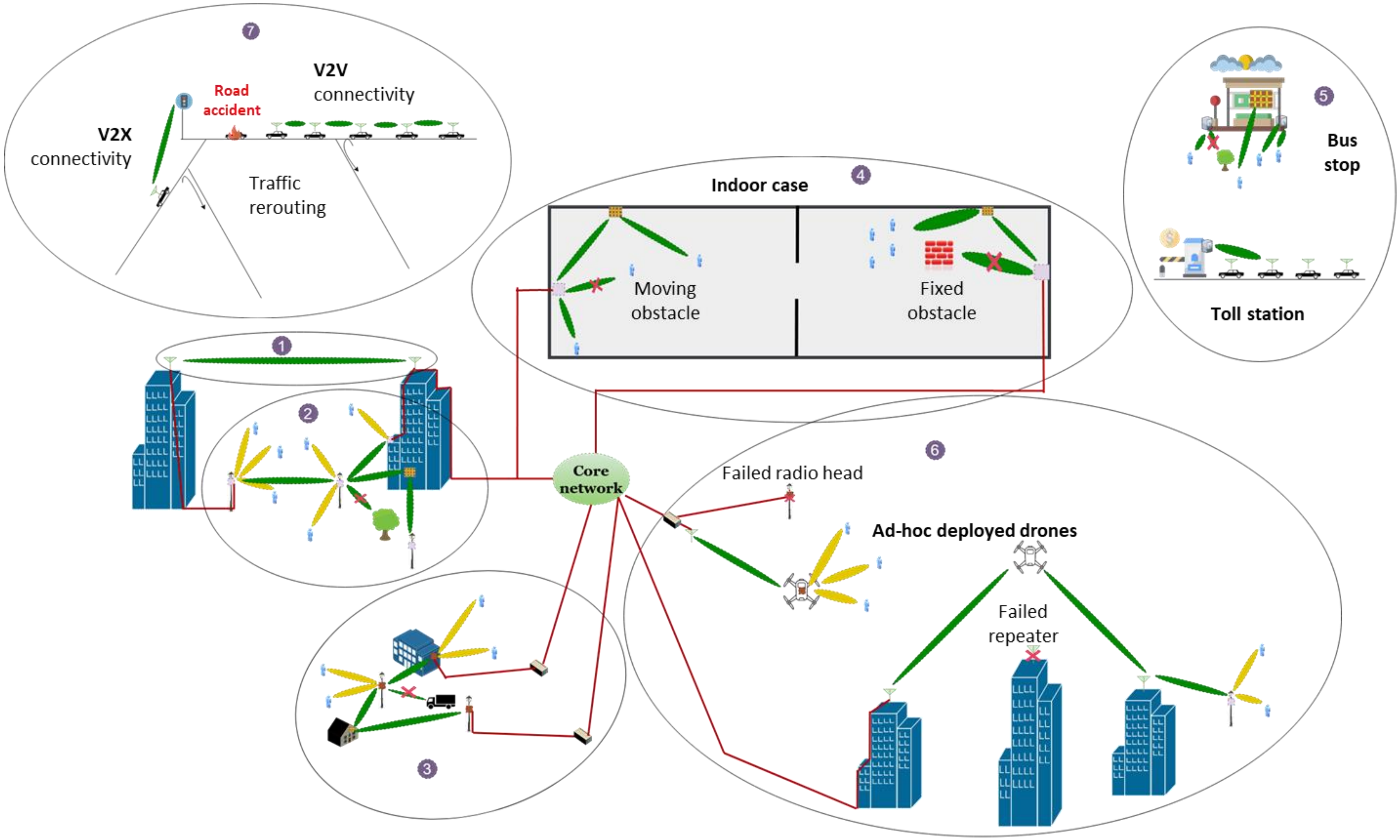

Figure 2 - ARIADNE Use Cases and deployment scenarios

In terms of deployment, the following two main scenarios are examined in ARIADNE for which a brief description is given below:

Scenario 1.1: Long-range LOS rooftop point-to-point backhauling

This examined scenario corresponds to long-range point-to-point rooftop backhauling in the D-band, as it is depicted in ellipse 1 of Figure 2 and in Figure 3.

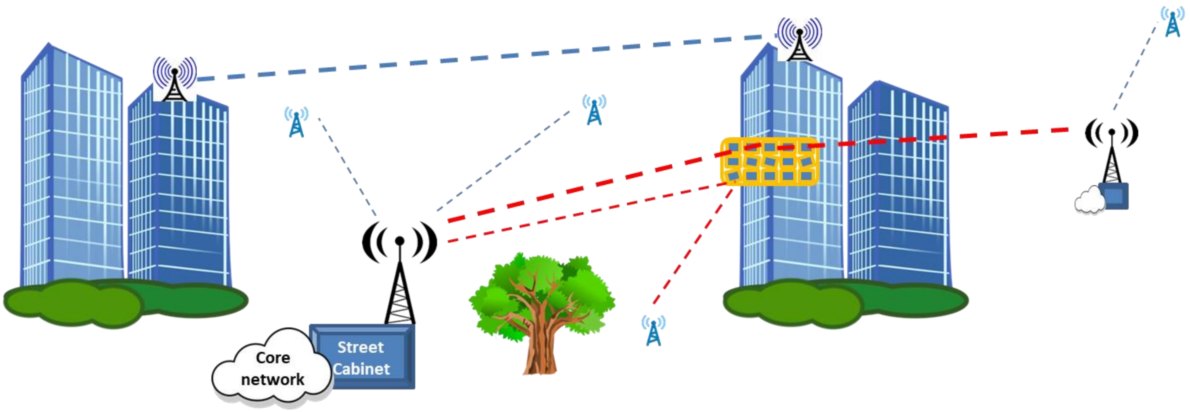

Figure 3 - Backhaul/fronthaul network with and without RIS

Scenario 1.2: Street-level point-to-point and point-to-multipoint backhauling/fronthauling

The examined scenario corresponds to street-level point-to-point and point-to-multipoint backhauling/fronthauling operating in the D-band in an urban setup. The corresponding backhaul/fronthaul nodes are mounted on street-level objects, such as lampposts, next to small-cell and remote radio head (RRH) nodes, as it is depicted in ellipses 2 and 3, respectively of Figure 2. Due to the size limitations of such objects, which limit the achievable dimensions of the corresponding backhaul/fronthaul nodes, together with the existence of obstacles in the radio path, such as buildings, the communication is limited to few hundred meters. Such communication can be either LOS or NLOS through RISs. In the latter case, when the LOS link between a transmitter and its intended receiver is blocked, either due to a fixed obstacle, such as a building or a tree, or a moving one, such as a tall vehicle, the communication is assisted through an RIS acting as a reflector that is mounted on some nearby surface, as it is depicted in ellipses 2 and 3 of Figure 2 and in Figure 3. In such a case, the links between the transmitter and the RIS as well as the RIS and the intended receiver are LOS.

Use case 2: Advanced NLOS connectivity based on metasurfaces

In the corresponding use case of ARIADNE, we consider RIS-based scenarios of advanced functionality of the RISs in the sense that they are dynamically reconfigured so to track slowly moving users. This reconfiguration occurs at a much higher pace than in the corresponding scenarios of Use Case 1, which creates substantial challenges regarding the type of switching elements among the unit cells that can achieve this and also the tracking of the position of users and the estimation of their channels that is required. The following two scenarios are examined that are briefly described below.

Scenario 2.1: Indoor advanced NLOS connectivity based on metasurfaces

Due to the slow mobility of several indoor users, we consider that the corresponding users can be served by D-band links originating from indoor small-cell base stations, as it is depicted in ellipse 4 of Figure 2 and in Figure 4. This, of course, assumes that both small cells and the mobile devices of users are equipped with D-band transceivers. Such a communication can occur either in LOS or NLOS conditions. The latter case is a quite plausible scenario indoors due to the various obstacles encountered such as walls and moving people that could block the LOS links. In such a case, RISs mounted on interior walls that act as anomalous reflectors assist the communication by creating alternative LOS hops.

Figure 4 – A possible indoor scenario with RIS

Scenario 2.2: Data kiosk

Data kiosks are entities that allow the transfer of a very large amount of data in a very short amount of time or offer very high data rate at extremely low latency. Depending on the kiosk functionality, the user can be advised to remain stationary when found in the range of the kiosk or to move adequately slowly so to be effectively tracked during the motion. The transferred content is capacity demanding and delay sensitive and can include various applications such as videos, movies, VR etc. Due to the requirement of the transfer to be completed in a short amount of time, such communication is envisaged to be realized in the D-band. In addition, to allow range extension of the data kiosks while at the same time counteracting possible blocked links due to passing users, for instance, we assume data kiosks that can steer their beams towards nearby RISs that act as reflectors and guide the redirected beams towards the intended users, as it is depicted in ellipse 5 of Figure 2.

Use case 3: Adhoc connectivity in moving network topology

An essential deployment of the D-band spectrum is envisaged to correspond to emergency scenarios in future networks. Regarding this, in ARIADNE, the following two scenarios are of interest and are briefly described below:

Scenario 3.1: Dynamic front/backhaul connectivity for mobile 5G access nodes and repeaters

Drones in future networks are envisaged as a way to extend or enhance coverage. They can be essential in emergency cases when backhaul/fronthaul nodes stop operating due to malfunctioning or physical disaster. For instance, one possible example is depicted in ellipse 6 of Figure 2 and in Figure 5. Due to the failure of a remote radio head, a drone is deployed with attached remote radio head so as to serve the affected users. The particular remote radio head is fronthauled to the respective baseband unit through a D-band wireless link.

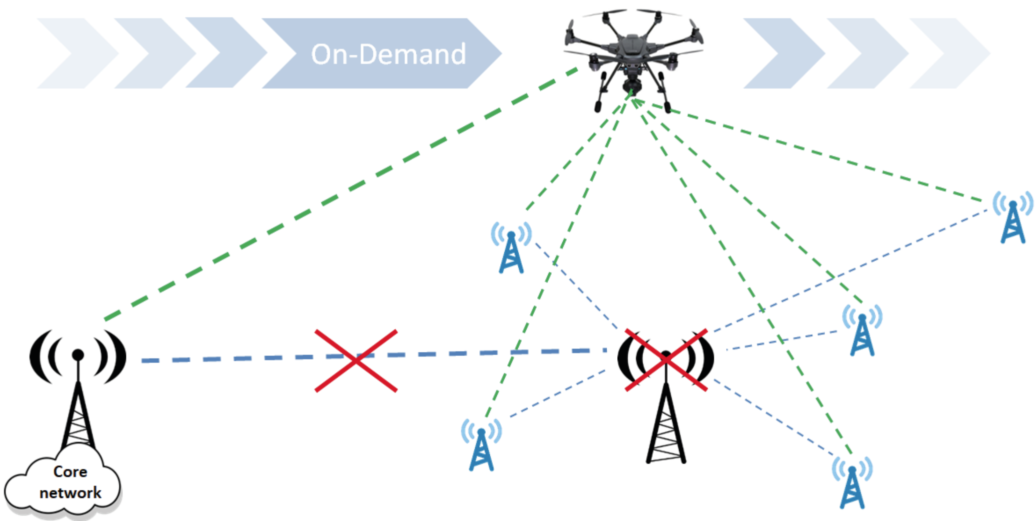

Figure 5 - Fronthauling topology (blue) replaced by alternative links (green) by using a drone

An additional example corresponds to the case of rooftop-based backhauling through repeaters. In the particular scenario that is also depicted in ellipse 6 of Figure 2, due to the failure of a repeater that serves the D-band communication between two rooftop backhaul nodes, a drone equipped with a D-band transceiver is deployed so as to act as a repeater.

Scenario 3.2: V2V and V2X connectivity

Vehicles can be equipped with D-band transceivers for reliable fast communication of road/traffic conditions to preceding cars, compromise between bandwidth/data rate and ranges in this frequency spectrum.

For instance, as it is depicted in ellipse 7 of Figure 2, in case of a road accident on a highway the leading vehicle that has a LOS view of the accident can obtain a real-time video streaming from the accident and the surrounding environment that is relayed via LOS D-band links to approaching vehicles. Based on such information, some of these approaching vehicles are able to move towards other directions so as to avoid traffic jam. This can be a typical example of a vehicle-to-vehicle (V2V) connectivity scenario.

In addition, another example is also depicted in ellipse 7 of Figure 2, where a traffic light that is located close to the accident dispatches the real-time video streaming concerning the accident to vehicles approaching from other directions. With such information, those vehicles are able to move towards other directions so as to avoid traffic jam. This can be a typical example of a vehicle-to-everything (V2X) connectivity scenario.