Control and Data Plane Separation for Interoperable Indoor Wireless Access Connectivity

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Abstract We present a centrally-controlled indoor network that harnesses data/control plane separation, virtualization of resources, and a high-capacity distribution architecture to achieve interoperability between OWC and competing wireless access technologies. Such a network could potentially support end-to-end delivery of heterogeneous services in the beyond-5G and 6G era.

Indoor Wireless Connectivity in the Era of Beyond-5G & 6G Networks

The current momentum of 5G research and commercial deployment is expected to accelerate the development of beyond-5G and 6G networks in the next decade. While 3GPP Release 17 and Release 18 will focus on beyond-5G features in the next 2-3 years, the standardization of 6G is expected to be finalized around 2028-2029 with commercial products expected from 2030 [1],[2].

A key vision of 6G networks is to realize seamless connection between the physical, digital and biological worlds. Example emerging new services and use cases include holographic teleportation services based on real-time fully-immersive human-to-machine technology, on-demand unmanned aerial vehicle services, fully autonomous transportation and logistics services, smart ambient connectivity across homes, buildings, and smart cities, and Internet-of-Everything/Senses with sight, sound, taste, smell and touch connectivity that is facilitated by extended reality, smart wearables, extended reality, and automation [1]–[5]. Such services demand extreme key performance indicators (KPIs) where by depending on the specific 6G service, a combination of unprecedented levels of capacity (> 1 Tbps), reliability (above 7 nines reliability), security, privacy, mobility (> 1000 km/h), coverage (~10 million devices per km^2 in dense areas), energy efficiency (10-100x more efficient than 5G), and low-latency (< 1ms) may be required [2].

As importantly, 6G will draw upon new technology enablers to realize end-to-end support of these new and dynamic services. Examples include terahertz communication technologies, AI-embedded distributed computing and resourcing, multi-stakeholder (e.g. network operators/service providers/local councils) management and operation, high precision telemetry, distributed orchestration and management, edge fusion, ultra-high capacity indoor wireless connectivity and tighter interoperability between heterogeneous network segments and their technology platforms.

Indoor wireless connectivity that harnesses the optical spectrum has been rigorously explored in both academia and industry in recent years, giving rise to optical wireless communication (OWC) technologies, such as free-space optics [6]-[8], visible light communications (VLC) [9],[10], and LiFi [11], that use strictly or a combination of visible light, infrared and/or ultraviolet spectra. The use of optics in OWC as a viable indoor wireless technology is seen as a natural extension to the optical core, metro, access, local area, enterprise, and more recently x-haul solution of 5G networks[12].

Generally benefitting from unregulated, limitless bandwidth, immunity to electromagnetic interference, low power consumption, low CAPEX and OPEX, and high level of security, each OWC technology mentioned above has its own unique merits and drawbacks [13]-[14]. With the aim to potentially support the extreme KPIs of 6G services, the focus of this paper will be on the interoperability of high-capacity OWC and competing wireless access technologies through a universal network architecture [15], [16] that can potentially facilitate flexible coexistence between 60GHz WiFi, VLC and IR-based OWC networks.

Universal network architecture for wireless access connectivity

Interoperability between different future high-capacity indoor wireless access technologies will be crucial to their successful deployment in the 6G era. Figure 1 illustrates our recently proposed universal network architecture that flexibly supports wireless access network technologies such as IR-based OWC, VLC, and 60GHz WiFi [15], [17]. The network architecture employs a centralized software and hardware resource pool, data plane separation, virtualization support and a high-capacity optic fiber distribution network to enable full-duplex data

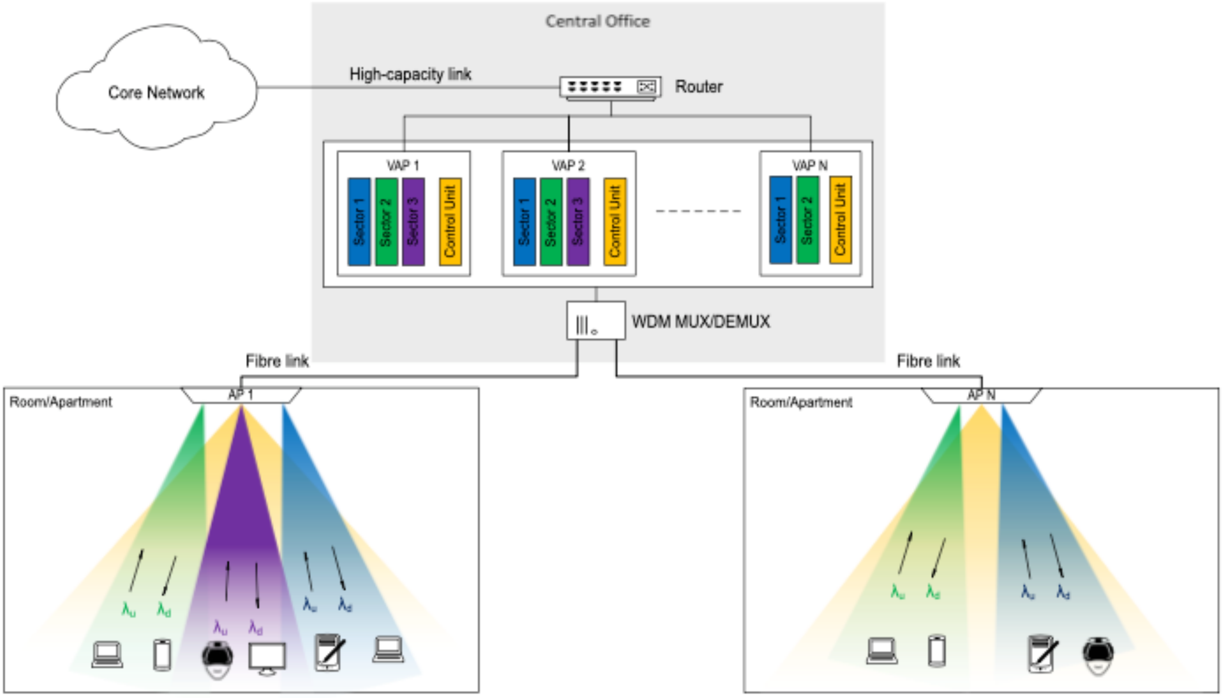

Fig. 1 Universal network architecture with data plane separation and virtualization support for interoperable wireless access connectivity.

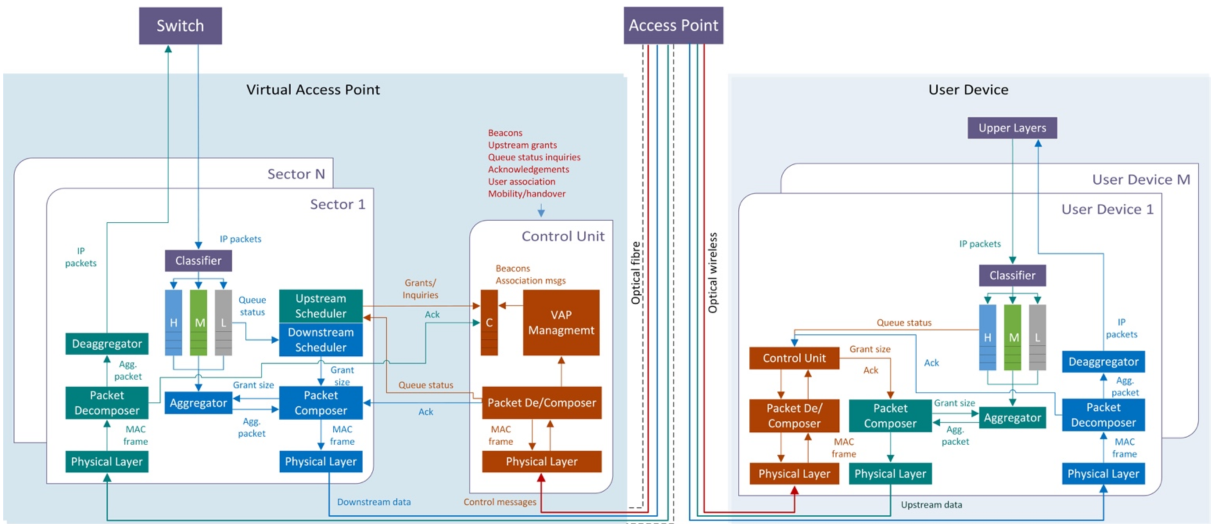

Fig. 2 Functional block diagrams showing the wireless connection between a physical access point (AP) and *M* end user devices of one of its sectors, and the optical connection between the AP to its Virtual Access Point (VAP) with *N* sectors and one control unit.

transmissions with low delays.

As shown in Figure 1, the central office (CO) connects the optical core network to indoor physical access points (APs) via a high-capacity wavelength division multiplexed (WDM) distribution fiber network. As an example, the CO can be located at the basement of a building. It houses centralized hardware, e.g. network switch/router, transceivers, wavelength multiplexers/demultiplexers, and computer processing resources to instantiate a number of virtual access points (VAPs) to coordinate functionalities of corresponding APs located at individual apartments/rooms.

Each physical AP is a ceiling-mounted wireless access point. It serves a small indoor coverage area which is divided into multiple sectors. In turn, each sector is served by two distinct narrow directional beams to realize full-duplex wireless data transmission (between the AP and end users of the sector) on the data plane. These narrow directional beams operate independently of each other and together with the orchestration at the CO via the VAP, sector resources at the physical AP can be dynamically and flexibly configured as required. For example, an increase in end user density or bandwidth demand within the coverage area of the AP will necessitate an increased in the number of sectors accordingly.

Overlaying on all sectors of each AP is a wider non-direct line-of-sight optical beam for control/management message exchange; this again orchestrated at CO and in particular by the control unit of the corresponding VAP . The control unit is responsible for the control and management of the AP. The wider beam covers all users within the AP, allowing exchange of control and management messages such as beacons, beam steering messages, *etc*, to be performed regardless of end-user location and/or transceiver orientation. The separation of the control and data planes removes bottlenecks in data transmission throughput that arise from control/management message overhead. Further, in the event of transceiver failure of one or more of the sectors, this control channel can be used to support data transmission as well. Finally, the wider beam transceiver is modulated at a lower order of modulation as compared to the narrow beam sector transceivers so that an end-user with low received signal strength can decode the beacon messages, initiate handshake and join the network. At the CO, the switch/router stores up-to-date information of each sector and it has the ability to direct any incoming packets to the relevant sector. An arriving packet from the core network will be forwarded to the relevant sector of the VAP by the network switch/router. Finally, the transceivers and hardware of the AP and end-user devices will be wireless technology specific.

Figure 2 illustrates the functional blocks of a VAP that comprises *N* sectors and one control unit and its optical connection to the physical AP. It also illustrates the functional blocks of *M* user devices that are wirelessly connected to one of *N* sectors of the physical AP. We implemented the universal network architecture as a new module in ns3 and the functional blocks modelled as C++ classes or functions [17]. With a control channel operating at 1 Gbps and data channels at 10 Gbps, Figure 3 shows simulation results that highlight the benefit of full-duplex operation facilitated by the architecture. Low latency performance in comparison to using a WiFi protocol as a reference, can be achieved under high network loads.

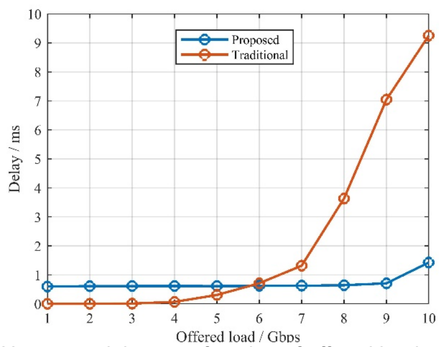

Fig. 3 Upstream delay as a function of offered load.

Summary

We discussed a universal network architecture with control data plane separation in conjunction with virtualization support and a high capacity distribution network. This architecture has the potential to realize interoperability between existing and future high capacity wireless access technologies and dynamic and flexible allocation of resources in response to changing user bandwidth demand.

Acknowledgement

We acknowledge the Australian Research Council (DP170100268) for funding this work.

References

[1] White paper on 6G Networking, 6G Research Visions, No. 6, 2020. [Available online]: http://jultika.oulu.fi/files/isbn9789526226842.pdf

[2] White paper on Key Drivers and Research Challenges of 6G for Ubiquitous Wireless Intelligence, Research Visions, No. 1, 2019. [Available online]: http://jultika.oulu.fi/files/isbn9789526223544.pdf

[3] E. Wong, et al. "The Role of Access Network Technologies for 5G and Beyond," *Proc. of CLEO-PR,* 2020.

[4] S. Mondal, et al., "Enabling Remote Human-to-Machine Applications With AI-Enhanced Servers Over Access Networks," *IEEE Open Journal of the Communications Society*, vol. 1, 889-899, 2020.

[5] E. Wong, et al., "Predictive resource allocation for Tactile Internet capable passive optical LANs," *J. Lightw. Technology*, 35 (13), pp. 2629–2641, 2017.

[6] K. Wang, et al., "High-speed indoor optical wireless communication system employing a silicon integrated photonic circuit," *Optics letters*, 43 (13), 3132-3135, 2018.

[7] K. Wang et. al., "4 x 12.5 Gb/s WDM Optical Wireless Communication System for Indoor Applications," *JLT*, 29 (13), 1988-1996, 2011.

[8] T. Song, et al., "Performance Analysis of Repetition-Coding and Space-Time-Block-Coding as Transmitter Diversity Schemes for Indoor Optical Wireless Communications," *JLT,* 37(20), pp. 5170-5177, 2019.

[9] Y. Tanaka, et al., "Wireless optical transmissions with white colored LED for wireless home links," *Prof. IEEE Int. Symp, on Personal Indoor and Mobile Radio Comms.*, vol. 2, pp 1325-1329, 2000.

[10] S. U. Rehman, et al., "Visible Light Communication: A System Perspective—Overview and Challenges," Sensors (14248220) 19, pp. 1153, 2019.

[11] H. Hass, et al., "What is LiFi?", *J. Lightw. Technology,* 34(6), pp. 1533-1544, 2017.

[12] C. Lim, et al., "Evolution of radio-over-fiber technology, *JLT,* 37(6), pp. 1647-1656, 2019.

[13] M. Z. Chowdhury, et al., "A Comparative Survey of Optical Wireless Technologies: Architectures and Applications," IEEE Access, 6, pp. 9819-9840, 2018.

[14] T. Koonen, "Indoor Optical Wireless Systems: Technology, Trends, and Applications", *J. Lightw. Technology*, 36, pp. 1459-1467, 2018.

[15] A. Nirmalathas, et al., "Gigabit/s Wireless Access and Indoor Networks," *Proc. of OFC*, M2H.5, 2020.

[16] W. Saad, et al., "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems," *IEEE Network*, 134-142 2020.

[17] S. Edirisinghe, et al., "A Novel Network Architecture for Indoor Optical Wireless Communication," *Proc. of the Global LIFI Congress (GLC)*, 2019