

A Resources Allocation Scheme For Joint Optical Wireless Transport Networks

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Abstract— As the future of networking dives into a new era of connecting every single physical device into the internet termed Internet of Things (IoT), this significantly means a rapid increase in the number of online connected devices, which leads to more bandwidth hungry and data consuming devices. The fifth generation (5G) of mobile communication has been deployed already in multiple countries, therefore researchers have migrated their focus to the sixth generation (6G) of mobile communication to cater for extensive coverage and massive number of IoT devices. A promising architecture and technology to cope with massive number of online devices and extensive coverage is a joint optical wireless transport network which offers comparably ultra-high systems capacity and extremely low latency while maintaining an improved quality of service. Furthermore, an optical wireless transport network can accommodate high speed mobility for frequently moving end user devices which is essential for 6G. In this paper our focus is to explore and propose an ultimate optical wireless transport network architecture scheme that will cater for IoT as well as networks beyond 5G. We thus propose an innovative Optical-Backhaul and Wireless Access (OBWA) network architecture as a favorable solution for future networks. We further present a joint channel and route allocation (JCRA) scheme for achieving optimal quality of experience. Performance evaluation of the proposed JCRA scheme for OBWA network architecture show a significant improvement in the network throughput as well as the network end-to-end delay despite varying load traffic or varying flow channels.

Keywords— Resources allocation, Optical Wireless Transport Network (OWTN), Internet of Things (IoT), Sixth Generation(6G).

I. INTRODUCTION

The fifth generation (5G) of mobile communication network has already been deployed from 2020 and still continues even today, but unfortunately the demand for data is still increasing and will continue even worse by 2030. Researchers are already working towards the sixth generation (6G) of mobile communication which aims to be deployed beyond 2030. According to the ITU-Report [1-3], monthly data traffic usage per user will approximately be 257 gigabytes (GB) by 2030 and the overall mobile data traffic per month will be approximately 5036 exabytes (EB) as shown in Fig. 1 and Fig. 2 respectively. The rapid increase in data consumption by 2030 will clearly be due to having a massive number of physical devices connecting to the internet because of the Internet of Things (IoT) paradigm [5-6]. Additionally, this factor will increase further beyond 2030 with the introduction of Internet of Everything (IoE), which aims to connect everything and everyone to the

internet. The drastic increase in data traffic clearly shows the necessity of having a state-of-the-art network architecture to cater for future network demands.

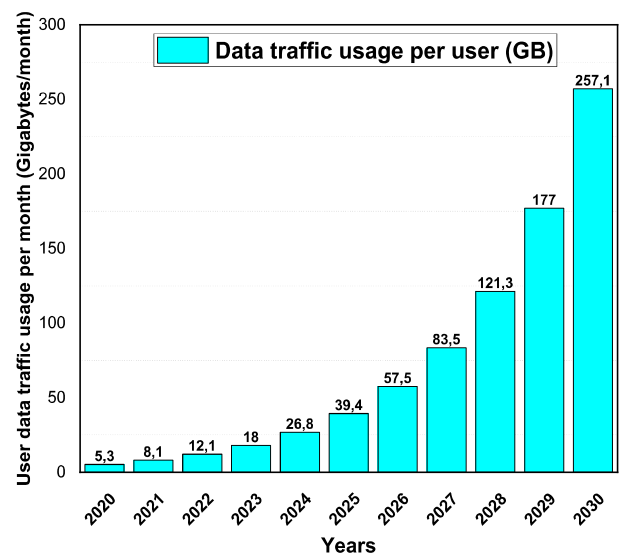


Fig. 1 Estimation of the user data traffic per month from 2020 to 2030 based on ITU-R Report M.2370-0

The optimum solution that has emerged over the years which is capable of handling high capacity and high-density networks is the optical spectrum. A joint wireless network based on an optical backbone is termed as an Optical Wireless Transport Network (OWTN). This hybrid network approach combines wireless front-end access network with high capacity optical backhaul network to provide much improved capacity in a much-reduced cost, this is because optical fibers are deployed as far as possible from the central office to the end-users and the front-end provides wireless access to the end users which results in lower costs due to lower deployment of optical fibers as compared to conventional passive optical networks (PON) whereby optical fibers are deployed up to the optical network units (ONU) such as fiber to the home [4][7]. This joint network paradigm promises to offer exciting new services with extremely high network capacity and bandwidth, massive number of device connectivity, extremely secure networks, ultra-low latency, high quality of experience, and finally very low energy consumption. Therefore, this paper aims to provide an optimal solution for future networks, this optimal solution is based on a joint optical and wireless network architecture as well as a resources allocation scheme, which

will enhance the overall operation of the architecture to cope with IoE/IoT as well as networks beyond 5G.

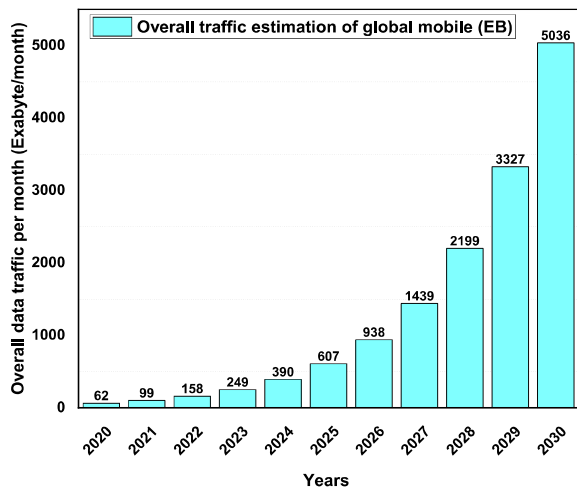


Fig. 2 Estimation of the overall mobile data traffic per month from 2020 to 2030 based on ITU-R Report M.2370-0

A. OWTN Application Platform

There is a wide range of platforms where OWTN can be applied to improve performance and achieve future demands [8-10]. Fig. 3 shows several applications for OWTN such as in mission critical applications for e-Health in hospitals, smart homes and smart factory, autonomous vehicles and transportation, industrial plant operation and agricultural applications. For these applications to be realised, OWTN must be integrated with innovative technologies such as Device-to-Device (D2D) communication, machine-to-machine (M2M) communication, vehicle-to-infrastructure (V2X) communication, or even machine to user communication. These applications require extremely low latency, ultra-high-security and massive system capacity such as in remote diagnostics in e-Health and self-driving cars in autonomous vehicles, and all these services are possible through optical and wireless transport networks.

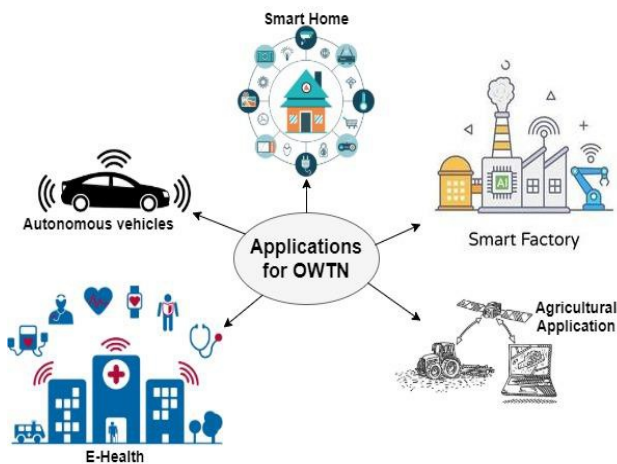


Fig. 3 Applications for OWTN

B. OWTN for 6G and IoT

OWTN possesses the necessary transportation ingredients for creating a heterogeneous network architecture by combining ultra dense cells, nested pico cells, nested femto cells and adapting new technologies such as light fidelity (Li-Fi) to cater for networks beyond 5G as well as massive connectivity of IoT devices. Li-Fi technology is a wireless communication that is similar to wireless fidelity (WiFi) and can provide extremely high data rates transmission for indoor or short-range communication. Furthermore, Li-Fi can provide ultra-dense hotspot cells to meet the requirements for networks beyond 5G and IoT. OWTN is clearly a promising technology for future networks and for IoT because it offers densified cells in the wireless access network and optical services in the backbone core network [7][11].

This paper is further organised into sections as follows: Section II discusses the related literature work on the topic, Section III proposes a favourable solution as a hybrid Optical-Backhaul and Wireless Access (OBWA) network architecture for future networks, Section IV proposes and describes a joint channel and route allocation (JCRA) scheme to be adopted by our OBWA network architecture, Section V evaluates the performance of the proposed joint channel and route allocation scheme in the OBWA network architecture, and finally Section VI concludes the paper.

II. RELATED WORKS

In [12], the authors integrate software defined networking (SDN) with a converged 5G fiber-wireless (Fi-Wi) network. Their approach was based on leveraging decoupling features introduced by SDN, whereby the infrastructure layer can be decoupled from the application and network services resulting in a network that is centrally controlled by an orchestrator. Their work mainly focuses on a practical deployment of a centralised orchestrator for a converged Fi-Wi 5G network. The authors further demonstrated a trial experiment using an SDN controller integrated with Fi-Wi lab equipment. Their work proved the practical applicability of SDN in a Fi-Wi network, which proved that a Fi-Wi network can be controlled by a centralised controller. However, this work mainly focuses on SDN integration with fiber networks and wireless networks for 5G applications, but the authors did not propose any holistic or joint network architecture which incorporates the two networks which is optical and wireless. The authors at [13], addresses the research directions of optical wireless hybrid networks and key research issues are discussed. In their work, Optical wireless communication (OWC) is discussed as a solution for the future to accommodate massive connectivity of the IoT and networks beyond 5G. Their study uses advantages of OWC to create a hybrid optical and wireless network which aims to improve network throughput. A detailed technology overview of optical and wireless hybrid network is given, where the wireless technology such as small cell, wireless fidelity (Wi-Fi), macro cell and Bluetooth is discussed in detail, as well as optical based visible light communication such as light fidelity (Li-Fi), free space optical (FSO), and optical camera communication (OCC) is also discussed for co-deployment in hybrid networks. Finally, the authors also addressed hybrid acoustic and optical systems for under water acoustic communication. Their work is significant

because it provided a novelty on optical and wireless hybrid networks. However, in their work again the authors here failed to propose any holistic network architecture combining all these technologies into one, instead they discussed the advantages brought by each individual technology whether its wireless or optical. The author at [14], reviews a series of innovative and enabling optical network technologies for any-haul (x-haul) in current and future networks. The author addresses high throughput enabling technologies for mobile x-haul to cater for networks beyond 5G, this is achieved through bandwidth-efficient mobile x-haul using hybrid digital-analog radio-over-fiber (DA-RoF), wavelength division multiplexing (WDM), ultra-low latency 50 Gbps passive optical network (PON) and network slicing with fine granularity in the optical transport network. The authors at [15], propose a resources allocation scheme termed modified Resources Allocation (RA) which is based on supervised machine learning to improve QoS in 5G wireless networks. Their modified RA scheme uses a Random Forest Algorithm (RFA) with Signal Interference and Noise Ratio (SINR) and location co-ordinates to locate the exact position of the end users. Additionally, the modified RA scheme also predicts modulation and coding scheme for creating a connection between end users and base stations. Basically, their proposed scheme uses position-based estimates of the end user's devices to predict modulation and coding schemes. The authors further proposed a model evaluation which showed that their modified RA scheme performs better than traditional resources allocation schemes through improved throughput and energy efficiency. However, their results also showed a huge drawback whereby when the number of users increase then the performance of their scheme starts to deteriorate, which cannot support massive number of connected devices as in IoT networks. It is clear that there are many shortcomings in literature regarding a joint

optical/wireless holistic network for future networks which can offer high capacity transmission, limitless connectivity and low latency transmission, therefore, motivated by all the shortcomings in literature stated in this section, we then propose a holistic and innovative architecture combining both the optical and wireless networks, furthermore we propose a resources allocation scheme for maximising throughput while minimizing end-to-end latency.

III. A JOINT OPTICAL-BACKHAUL AND WIRELESS ACCESS NETWORK ARCHITECTURE

Global coverage, limitless connectivity and near instance response time are few major demands that need to be addressed by new innovative architectures for supporting networks beyond 5G. Basically, the new innovative architectures must be capable to handle new technologies such as IoT and artificial intelligence (AI) systems efficiently. Furthermore, IoT will connect billions of devices, which brings a question of security measures in such a massive network. After careful considerations of these factors and demands, we propose an innovative architecture-of-architecture referred to as a joint Optical-Backhaul and Wireless Access (OBWA) network architecture as depicted in Fig. 4. We propose this hybrid architecture as a possible solution for the future to leverage on both worlds, where, “wireless is essential for optical” in order to minimise cost and achieve greater geographical coverage, and the “optical is essential for wireless” in order to achieve greater bandwidth availability.

This architecture adopts new technologies in the access network such as D2D communication, V2X communication, M2M communication and LiFi for close range communication. Moreover, new efficient technologies are adopted in the core network such as flexible adaptive optical

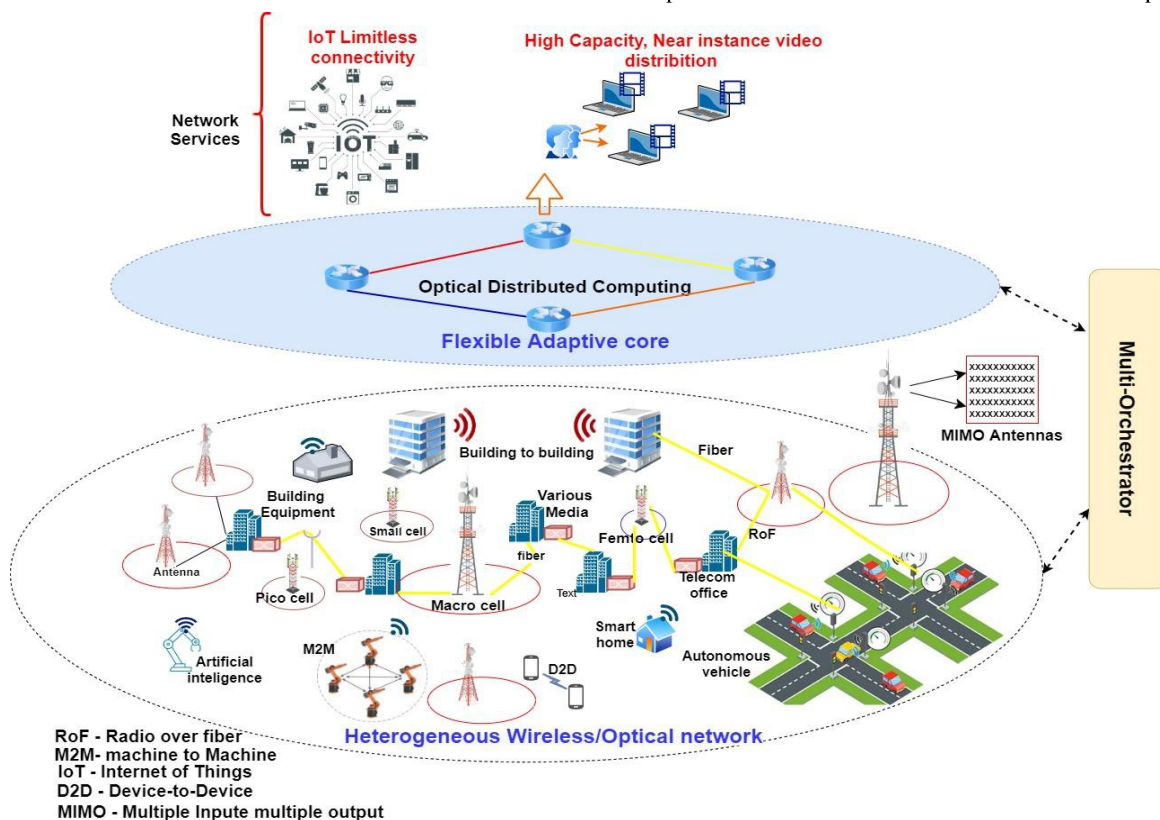


Fig. 4 A joint OBWA network architecture

networking. Furthermore, the joint OBWA architecture is designed to be environmentally friendly by improving the energy efficiency through the use of D2D communication in which devices directly communicate with each other and bypassing high power base station in the network. This architecture is heterogeneous in a sense that it uses densified micro cells, pico cells and femto cells to improve coverage. Moreover, in the optical core network, intelligent techniques such as network demand adaptation have been added to improve the flexibility of the network hence improving the resources allocation of the overall network. Finally, the OBWA architecture leverages on the superiority of software defined networking (SDN) by adopting a centralised controller termed the multi-orchestrator which works with function dedicated controllers for achieving energy efficient wireless control, flexible optical core network control and resource management control.

The multi-orchestrator can be described as the intelligence of the entire network because it oversees the optical core as well as the wireless access network which allows for much improved resources allocation. The ability of the multi-orchestrator to have an overlay view of the entire network is clearly significant as it can improve on the network routing as well as load balancing in the network.

The backbone network is a flexible adaptive optical core hence this improves the overall network utilization of resources, additionally, the adoption of optical distributed computing in the backbone allows for transmission with near instance response time which means this architecture can support mission critical applications such as remote hospital diagnostics and operations as well as self-driving cars. Furthermore, one other significant feature of this innovative architecture to note is the use of massive MIMO (multiple input multiple output) antennas on the base station. Massive MIMO which uses multiple transmitting and receiving antennas can significantly improve the channel capacity and the system spectrum utilization rate while maintain lower transmit power [16-18]. The joint OBWA network architecture clearly is an innovative architecture for current and future networks as it promises to services future demands for IoT limitless connectivity, high-capacity transmissions with ultra-low latency.

IV. A JOINT CHANNEL AND ROUTE ALLOCATION SCHEME FOR THE OBWA NETWORK

In a telecommunication network, most of the bottleneck, such as delays and throughput, occurs in the wireless mesh network section of the telecommunication system, therefore, it is significant to have a mechanism scheme that will have near instant delay time and maximise throughput performance in the entire network [19-22].

The total delay (D_T) is the sum of the average queuing delay (D_Q) and the access delay (D_A), where the queuing delay is the time in seconds in which a packet must wait in a queue before it is first in line in a queue to start contending for a channel, and the access delay is the time in seconds in which the packet must wait in front of the queue before the channel contention is resolved and the channel is allocated to the packet and there after transmission can proceed [19]. The total time for a packet to move from source to destination depends on active neighbour nodes of both the sender (n_a) and the receiver (n_b) because the packet is only transmitted if

the receiver is allocated the channel after sending a 'clear to send' reply. We can therefore approximate the total delay (D_T) as follows:

$$D_T(n_a, n_b) = A(n_a^2 + n_b^2) + B(n_a + n_b) + C \quad (1)$$

Where A, B, C depend on the load variations.

Assuming a multi-channel OBWA system, we further determine quality (Q) of the route (R) based on the route quality metric for route (R) of length (l) as follows:

$$Q(R) = \frac{\prod_{f=1}^l P_s(I_f)}{\sum_{f=1}^l D_T(n_{af}, n_{bf}) + \sum_{f=1}^l S_d * y_f} \quad (2)$$

Where, f is a link from source to destination or gateway, $P_s(I_f)$ is the probability of success in the link, I_s is a set interferers, $D_T(n_{af}, n_{bf})$ is the total delay with active neighbours from source (n_{af}) to destination (n_{bf}), S_d is the switching delay from one channel to another and Y_f is a binary variable representing 1 when link f is active. Using the predefined parameters, we thus propose a Joint Channel and Route Allocation (JCRA) protocol scheme. The joint channel and route allocation protocol is a reactive switching protocol which aims to maximise the throughput while minimising end-to-end latency [19]. This routing protocol follows 3 rules namely, route discovery, route selection and route maintenance.

A. Route Discovery

Initially a source node may not have a specific route to any gateway destination, therefore, in this protocol a source node will broadcast a route request (RR_{eq}) packet to all neighbouring nodes. The RR_{eq} packet contains significant fields such as RR_{eq} packet ID, source address, destination address, number of active neighbouring nodes (N), the cumulated probability of success (P_s) in the current route, acquired total delay (D_T) in the current route, and the stamp-time (time when the RR_{eq} packet was generated) which is used to prevent unnecessary overflow of RR_{eq} packets. The parameters N , P_s , D_T , and the stamp-time are all initialized by the source node, where N is initialized to the number of neighbouring nodes which are ready or in an active state, P_s probability is initialized to be 1, D_T is initialized to be 0. While the RR_{eq} packet is being routed, the intermediate nodes will update the gathered delay (D_T) and the probability (P_s) based on the previous node status before forwarding it to the next node. The RR_{eq} packet ID together with the source address identifies a unique route request. Noting that an intermediate node cannot receive the RR_{eq} packet more than once, if this happens, it discards it, this process is significant in-order to avoid excessive broadcast of packets. These principles are followed by all intermediate nodes until the RR_{eq} packet reaches the destination gateway.

B. Route Selection Protocol

The destination node or gateway will wait for a specific number of RR_{eq} packets, in our work we will assume 10 RR_{eq} packets for simulation purposes. Once all RR_{eq} packets are received by the destination node, then a backtracking or comparing algorithm is computed on all routes located by the RR_{eq} packets. Thereafter, the best route is chosen based on the highest route quality (Q). After choosing the channel with highest Q , the destination gateway sends a route reply

packet (RR_{ep}) back on the same chosen route. The RR_{ep} packet comprise of source address, destination address, channels assigned and stamp-time. Once the source receives the RR_{ep} packet, thereafter, starts sending packets of data through the same chosen path.

C. Route Maintenance

It is significant to always maintain an updated routing table, therefore if a routing table is unused for a long period of time, then the routing table entry is cleared. This feature is significant to improve the robustness of the scheme against temporary changes of the wireless channel caused by constantly moving end users. Thus, after a long period of time, a source router may be required to establish a new quality route.

V. PERFORMANCE ANALYSIS

In this section we evaluate the performance of JCRA scheme compared to other schemes such as single channel schemes and random channel schemes. The simulations are based on NS-3 simulator, for simplicity purposes, we have assumed parameters in table 1 for simulation. Our performance evaluation is based on the overall throughput and the end-to-end latency under different number of flows, different loads, and different number of channels.

Parameter	Value
Total nodes	30
Total RR_{eq} packets	10
Data packet size	1000 bytes
Bandwidth	6 Mbps
Noise floor	-101 dBm
Queue length	200 (Max)
Active time	0.5 s
De-active time	0.5 s
Transmit power	20 dBm
Transmission rate	185 Kbps

Table 1 Simulation Parameters

A. Throughput and latency for different number of flows

Fig. 5 and Fig. 6 shows the performance of the JCRA scheme under different number of flows for the throughput and end-to-end latency respectively. From Fig. 5 we can observe that the JCRA scheme out-performs other single channel schemes in terms of throughput, while also in Fig. 6 the JCRA scheme outperforms in terms of end-to-end delay. Our proposed scheme clearly improves the network throughput twice more compared to single or random channel schemes, this is due to our JCRA protocol based on efficient routing.

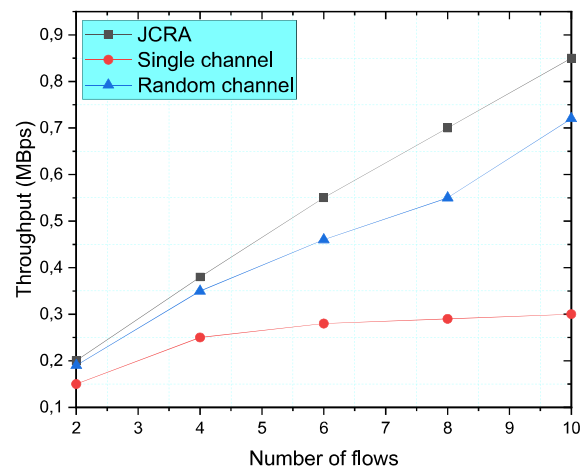


Fig. 5 Comparison of throughput with different number of flows for multi-channel OBWA network

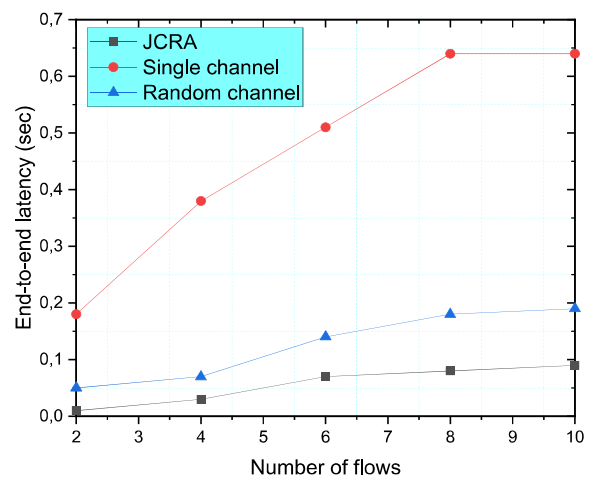


Fig. 6 Comparison of end-to-end latency with different number of flows for multi-channel OBWA network

B. Throughput and latency for different loads

Fig. 7 and Fig. 8 shows the performance of the JCRA scheme under different loads for the throughput and end-to-end latency respectively. From Fig. 7 we can observe that the JCRA scheme out-performs other single channel schemes in terms of throughput, while also in Fig. 8 the JCRA scheme out-performs in terms of end-to-end delay. While the simulated evidence may be equivalent on light network load, but as the load increases, it becomes clear that the JCRA scheme performs much better in terms of throughput as observed in Fig. 7. The performance is improved about four times compared to single channel scheme in terms of throughput. On the other hand, the end-to-end delay is significantly improved by at least a factor of three compared to single channel scheme.

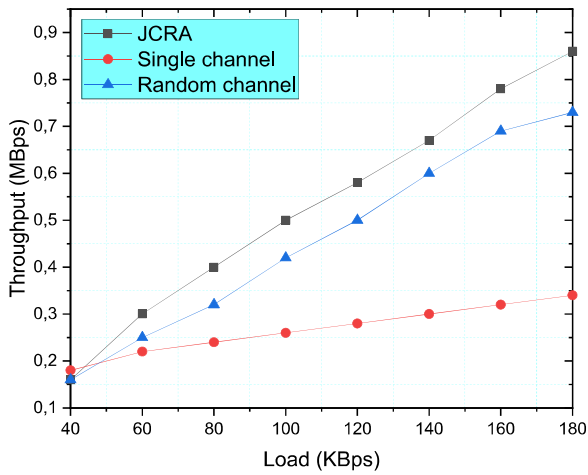


Fig. 7 Comparison of throughput with different loads for multi-channel OBWA network

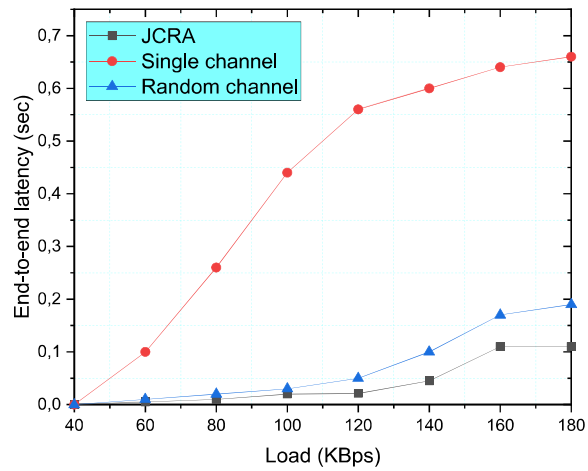


Fig. 8 Comparison of end-to-end latency with different loads for multi-channel OBWA network

C. Throughput and latency for different number of channels

Fig. 9 and Fig. 10 shows the performance of the JCRA scheme under different number of channels for the throughput and end-to-end latency respectively. From Fig. 9 we can observe that the JCRA scheme out-performs the random channel scheme in terms of throughput, because of reduced channel contention and network interference. It can be observed that the network throughput is improved about 3 times, while the traffic delay is reduced about 2 times.

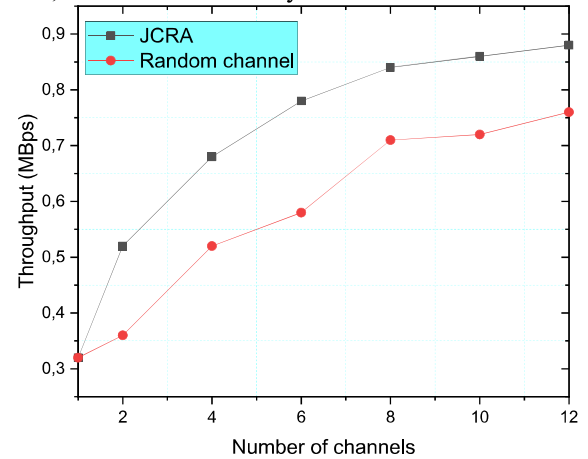


Fig. 9 Comparison of throughput with different number of channels for multi-channel OBWA network

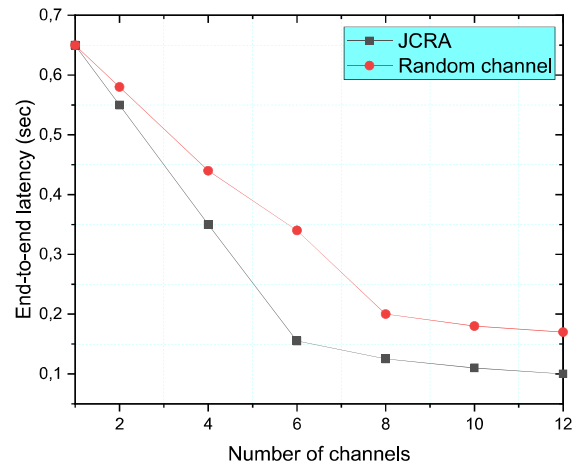


Fig. 10 Comparison of end-to-end latency with different number of channels for multi-channel OBWA network

VI. CONCLUSION

In conclusion, our work proposed a holistic network architecture referred to as a joint OBWA network architecture that is capable to accommodate IoT limitless connectivity and beyond 5G networks. Our proposed architecture incorporates innovative wireless technologies such as D2D communication, M2M communication, V2X communication, massive MIMO antennas, RoF and indoor communication such as Li-Fi, on the other hand, the backbone network adopts flexible and adaptive optical core. Furthermore, the proposed network architecture also shows a compromise between network cost and quality of service due to the hybrid deployment of both the optical and wireless networks. Finally, we proposed a Joint Channel and Route Allocation (JCRA) scheme, which is based on three protocols namely, route discovery, route selection and route maintenance which aims to improve throughput and minimise the total delay. The performance evaluation results proves that the JCRA outperforms single channel schemes in terms of throughput and end-to-end latency with different load, different number of channels and different number of flows.

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