Experiment on High Capacity Backhaul Transmission Link Aggregation Solution for 5G Networks

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***Abstract*—Nowadays, commercial 5G networks are starting to grow up rapidly. Requirements such as 1-10Gbps connections to endpoints, one millisecond end-to-end round trip delay - latency, 1000x bandwidth per unit area, 10-100x number of connected devices, 99.999% availability, 100% coverage, 90% reduction in network energy usage also extended compare to 4G networks. Existing microwave link bandwidths can no longer support ever-escalating requirements for 5G Backhaul capacity due to exponentially growing demand for mobile traffic by the arrival of the new portable gadgets. Spectrum resources of typical frequency bands (6 to 42 GHz) are proving insufficiency for providing high microwave backhaul capacity, making network backhaul capacity expansion increasingly more difficult. Face with the challenges, This paper presents an experiment on 5G Backhaul Small-Cell, includes an advanced Microwave Link Aggregation (MLA) technique to provide enough Backhaul capacities for 5G network. In this experiment, Mentum Ellipse used as a microwave planning tool for analytical simulation for proposed link aggregation, which offers 6.27 Gbps. The pilot implemented in the dense urban area delivers 6.073 Gbps in the proposed Cross Dual Band Link Aggregation (CDBLA) solution. CDBLA enables the integration of Common-Band microwave (CBM) (6 to 42 GHz) and E-Band microwave (EBM) (71 to 76 and 81 to 86 GHz) into one high capacity link to support large bandwidth and long-distance transmission.**

I. Introduction

5G is the next-generation cellular network that is expected to be highly efficient and fast, as well as being able to support more users, billions of smart devices, more services, and new use cases without a corresponding impact on the cost. Research and standardization work has been addressing from radio spectrum allocation, densification, massive multiple-input-multiple-output (MIMO) antenna, carrier aggregation (CA), inter-cell interference mitigation techniques, and coordinated multi-point processing[1], [2], [3]. In Addition, a new network bottleneck has emerged: the Backhaul network which will allow to interconnect and support billions of devices from the core network[4]. Up to current 4G cellular networks, the significant challenges to meet the Backhaul requirements were capacity, availability, deployment cost, and long-distance reach[4]. However, as 5G network capabilities and services added to 4G cellular network, the Backhaul network would face additional ultra-interconnection nature of the network challenge, resulting in Microwave Backhaul network need to maintain multi-Giga traffic from the network hubs to today's cellular networks that are infeasible to meet this requirement in terms of capacity, availability, latency, and cost-efficiency.

Previous studies achieved high data rates by combining new technologies such as small cell, millimetre wave (mmWave), full-duplex, beamforming (BF) and MIMO networks[5], [6]. The previous experiment in [7] has transmitted 1Gbps throughput over the frequency range without mobility over 200 meters in non-line of sight and 1.7 Km in line of sight (LOS) mmWave technology at 27.925 GHz with 4×8 planar array prototype to provides acceptable performance. Regarding [3], the mmWave radio frequency signal is more sensitive to path losses such as building and environment blockage. Therefore, it presents a shorter distance between base stations and users, which yields the advent of small cells[7], [8]. Furthermore, in [9] that 5G base station used massive MIMO, the distance between small cells and users decreased more. As a result, in this paper we experiment microwave interface with aggregation techniques between radio base stations and 5G small cells to eliminate short distance and low throughput issue.

This paper introduces the advanced microwave link aggregation solution between 5G small-cells and radio base stations compare to the previous works. In section II, remarkable previous approaches and scenarios are studied and analyzed for 5G Backhaul implementation, then our advanced scenario and CDBLA model is introduced. In part III, the proposed microwave link aggregation is designed and analyzed in a software tool. In the next section, the proposed solution is implemented and measured in a practical location. Finally, the conclusion results and comparison with classical solutions presented in section V.

II. Methodology

A. 5G BACKHAUL TOPOLOGY

Mobile and fixed broadband networks are continually evolving, leading to an exponential increase in the Backhaul

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capacity of base stations. And as 5G fast approaches, the microwave is facing the growing challenges. Common-band microwave provides highly reliable transmission line. There are some techniques for Common-band microwave throughput enhancement such as carrier aggregation (CA), MIMO dual-band with V/H polarization and co-channel interference cancellation (CCIC) are discussed in [10], [11], [12]. Although these techniques increase throughput, its spectrum resources are still insufficient, and maximum throughput is $(< 2Gbit/s)$, making capacity expansion challenging to raise more.

E-band microwave supports up to 4.5 Gbit/s, which satisfies the throughput requirements of 5G. However, its reliability reduces by distance and rain fades. Moreover, frequency channel interference of adjacent links prevents using its full bandwidth (BW) capacity, making it incapable of meeting the medium-distance Backhaul requirements of small-cell stations[12]. So, we planned and experiment with a solution that combines the long-distance and high-reliability capabilities of common-band links with the high throughput of E-band links. Fig.1 shows our experiment small cell Backhaul network topology that base stations use fibre interface and proposed CDBLA to connect with core and small cells, respectively.

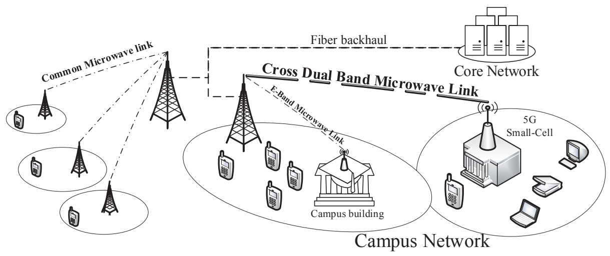


Fig. 1. 5G small cell Backhaul topology

B. PROPOSED MODEL

Analyzing environmental conditions such as fog or rain are particularly important when using super or extremely high frequencies (30-300 GHz)[13]. Losses incurred due to atmospheric or rain attenuation tend to increase at the mmWave wavelengths. Atmospheric attenuation is based on the ITU-R P676 that includes pressure, temperature and water concentration [14]. These parameters can be defined based on the location of the base station and the ITU classification by region. An approximate attenuation A_{rain} due to rainfall in this scenario is:

$$A_{rain} = \gamma_{rain} d_e \tag{1}$$

Where d_e is the effective length, the corrected value of the real path length, and also, it is the function of frequency and the actual climatic zone that formulated in (2):

$$d_e = \frac{d}{1 + {}^{d}/_{d_0}} \tag{2}$$

With d in kilometres and $d_0 = 35e^{-0.5R}$. Also, γ_{rain}(dB/Km) is based on coefficient α and β calculation for the rainfall intensity R(mm/h) that is defined:

$$\gamma_{rain} = \alpha(R)^{\beta} \tag{3}$$

In our experiment the implemented path length is 3.2km, therefore $d_e = 3$km. To estimate the long-term statistics of rain attenuation, the recommendation ITU-R-P530[15] can be applied for E-band as well[16]. The validity of (1) is fair enough if we consider long (12 months) measurement period with TableI value for α and β for frequency dependent coefficients for estimation specific rain attenuation for horizontal (H) and vertical (V) polarization.

TABLE I. REGRESSION COEFFICIENTS OF ITU-R P.838-1

Frequency(GHz)	β_H	β_V	α_H	α_V
18	0.0751	0.0691	1.099	1.065
80	0.975	0.906	0.769	0.769

Rain attenuation at specific mmWave frequencies impacts the accuracy of predictions. Rain attenuation for different rainfall rate R can be found in ITU-R recommendation [14], [15] as shown in Fig.2. The rain attenuation is very significant in mm-waves. For example, rainfall rates of medium (12.5 mm/h) and downpour (50 mm/h) yield to about 7 and 20 dB/km attenuations in E-band at 70∼80 GHz. For the case of severe (tropical) rainfalls (100 mm/h), the attenuation can reach up to 30 dB/km. However, this regularly occurs only in short bursts and is associated with a critical weather event that moves quickly across the link path[17]. Therefore, the rainfall rate is always associated with time probability or link availability of the average year.

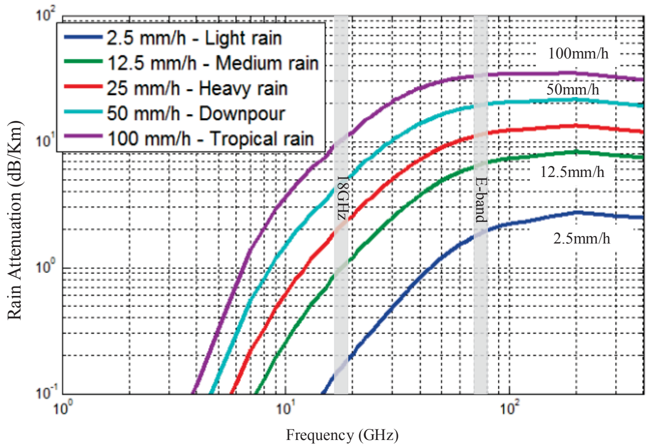


Fig. 2. Rain attenuation for different rainfall based on [18]. (Frequency 18G and E-band are specified for proposed CDBLA implementation.)

In general, Availability calculates as:

$$Availability[\%] = \frac{100(total\, usage\, time - downtime)}{total\, usage\, time}$$

Following ITU-R, the highest link availability is 99.999%. Thus, according to common Service Level Agreement (SLA) between a service provider and its internal or external customers the depicted in Fig.3; link availabilities between 99.99% and 99.999% or 0.01 to 0.001% (26.17 and 52.6 min) of yearly times are considered for the common-radio links and link availabilities between 99.9% and 99.99% or 0.1 to 0.01% (1hours and 8hours) of annual times are considered for the E-band radio links in this work. In this work, according to the cross-link aggregation in section I, we aim to reach average 99.99% in medium and downpour rainfalls environment in ITU-R P.530 7-16[15] rain model at the experimental 3.2Km link distance for customers with high priority services[19].

SLA	Availability/Annual down Time	
Low-priority Services	99.9%	8.76hrs
	E-Band	
High-priority Services	99.99%	52.6min
	CDBLA	
Voice	99.999%	5.3min
	Common Band	

Fig. 3. Validity of Network Performance

In order to ensure network performance is optimal, we validated hardware settings and network design by availability and Quality of Service performance (QoS). In our work, High-priority services transmitted over common-band microwave to achieve carrier-class availability and Low-priority services transmitted over E-band microwave to achieve large capacity. More validating, Adaptive modulation (AM) schemes considered as part of the link path or interference analysis tuning. In practice, by using adaptive modulation schemes, we improved the reliability and performance of a link. In this way, we can ensure that service is available. As depicted in Fig.4, if the E-band link quality degrades, the modulation scheme downshifts step by step, and link BW decreases gradually. Services on E-band links are switched to common-band links before E-band links are completely unavailable. In this case, high-priority services within available bandwidth are transmitted in hitless mode, and packet loss may occur in low-priority services. Providing to maximize throughput, we enabled AM to provide elastic capacity and also used QoS to guarantee key services. Then, we define certain radio types, configurations, used specific channels, and set the modulation and traffic parameters according to Adaptive Threshold:

$$\begin{aligned} Adaptive\,Threshold(dBm) &= Hysteresis(dB) \\ &+ Interference(dB) \\ &+ CINR(dB) \end{aligned}$$

In wireless communication systems, the performance and robustness are often determined by the signal-to-noise ratio (SNR) from radio link budget:

$$SNR = P_t + G_t + G_r - Pl - FM - L_{sys} - A_{rain} \quad (4)$$

Where P_t is the transmitter (TX) power, G_t and G_r are the antenna gains at TX and receiver (RX), P_L and F_M

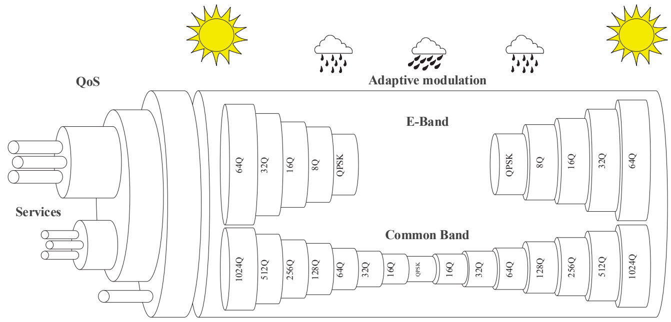


Fig. 4. Adaptive modulation and QoS

denote path loss and fading margin in channel, the system loss L_{sys} include noise power $N_0 = 10log_{10}(kTB + NF)$, Where $T = 290k$ and noise figure $NF = 6dB$ and implementation loss (IL) at TX and RX, and A_{rain} is rain attenuations in radio link.

As transmission power is restricted and path loss in E-band is very high, the antenna gain becomes very important in guaranteeing long-range point-to-point (PtP) radio links. In the following, the required combined TX-RX antenna gain (sum of antenna gains at TX and RX) is being determined based on link budget shown in Table 1, where the SNR is chosen as 10 dB for providing sufficient power margin in system design.

TABLE II. E-BAND AND COMMON-BAND RADIO LINK BUDGET

E-Band Radio Link Budget		Common-Band Radio Link Budget	
E-band	(71-86)GHz	Common-band	(17-18)GHz
SNR	10 dB	SNR	10dB
Antenna Gain	49.1 dB	Antenna Gain	38.3dB
Tx Power	10 dB	Tx Power	12dB
N_0	-52dBm	N_0	-61.5dBm
Pathloss	92.5 +20log(83.5GHz) +20log[d(km)]	Pathloss	92.5 +20log(83.5GHz) +20log[d(km)]
Channel BW	1000M	Channel BW	56M
Modulation	64QAM	Modulation	1024QAM
AM	Enabled	AM	Enabled
QoS	Enabled	QoS	Enabled
Fade Margin	20dB	Fade Margin	20dB
Configuration	1+0	Configuration	4+0
Rain Model	P530	Rain Model	P530
R	19.97mm/h	R	19.97mm/h
Availability	99.9−99.99	Availability	99.9−99.999

Our implemented CDBLA solution, which bonds the common frequency band (18GHz) together with E-Band (71-86 GHz) in a unique manner, offering increased throughput via CDBLA technique and advanced AM and QoS mechanisms to increase customer satisfaction and End-users benefit from the fast and stable 6Gbps transmission link. In our implementation, when the full capacity is not available due to high rainfall, AM and QoS will maintain the link and transmit high priority traffic. The CDBLA solution combines the long-distance benefit of common frequencies together with the substantial capacity advantage of the E-Band, ensuring efficient multi-Giga transmission. The schema of the proposed CDBLA is shown in Fig.5. In each node, we use intra-board radio link bonding to tailored and provide superior performance for the particular microwave transport solution concern. As a result, in our implementation, Link 1-2 and Link 3-4 in Fig.5 configured as an aggregated with XPIC[20] technology. In XPIC technique, a single RF channel utilized for two parallel wireless links, by means of parallel transmission on vertical and horizontal polarizations independently. Aggregated microwave radio links is the recommended approach. This scenario does not require sophisticated devices. XPIC engine consistently gets direct feedback about the wireless interface status and is also capable of adopting load balancing to the unstable wireless link condition (e.g. frequent modulation downshifting). However, XPIC aggregation on microwave radios often has the limited number of parallel links (usually two parallel links), lacks configuration flexibility and may bring some challenges to integration into the existing network. Though, in this experiment, we ran link aggregation on external switches to allow a higher number of parallel aggregated links (allows up to 4 parallel connections. With this XPIC aggregation, we reached to 1.7Gbps throughput that does not satisfy 5G small-cell requirements. So, we need to add E-band link to mentioned XPIC aggregation group as our complimentary solution. As a result, all links 1 to 5 grouped as CDBLA solution to pass full 6Gbps Ethernet traffic on air. In this scenario, the switching board collects Ethernet service bandwidth of each microwave link and allocates traffic based on the real-time Ethernet bandwidth over each member of microwave aggregation group to achieve almost the same bandwidth utilization on member microwave links. Moreover, we added load sharing regardless of Ethernet frame type or length, or whether they provide the same Ethernet bandwidth. Result of this action provide us with more flexible configuration with more throughput.

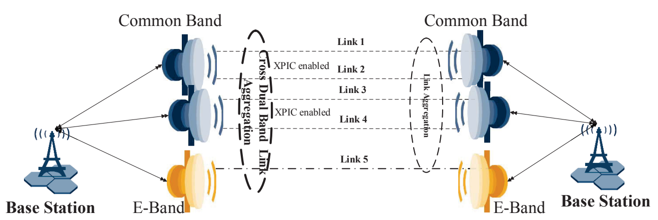
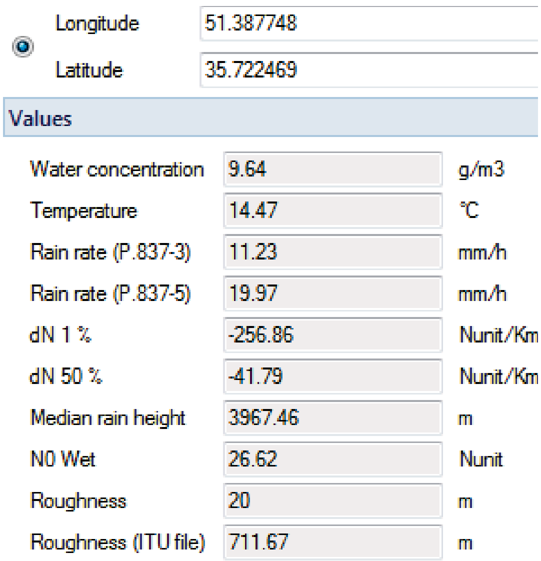


Fig. 5. Schema of Implemented CDBLA

III. Simulation Results

In this Experiment, Mentum Ellipse, microwave link and mobile backhaul solution engineering software for dimensioning, planning and optimizing is used to support the creation of accurate link budgets, atmospheric attenuation, selective frequency fading. The Fig.5 Shows simulated the microwave link aggregation with the distance of 3.2km. The designed parameters are simulated according to in TableII. Moreover, Fig.6 shows the simulation ITU recommendation values for our experienced location.

Fig.6 includes longitude and latitude value of CDBLA location. Water Concentration, Temperature value, Rain Rate, dN 1% is the refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year and dN 50% displays the refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 50% of an average year. Median Rain Height meters above sea level (AMSL) provided in recommendation ITU-R P.839[21], sea level surface refractivity value N_0 Wet, and Roughness value that obtained from the



Longitude	51.387748	
Latitude	35.722469	
Values		
Water concentration	9.64	g/m3
Temperature	14.47	°C
Rain rate (P.837-3)	11.23	mm/h
Rain rate (P.837-5)	19.97	mm/h
dN 1 %	-256.86	Nunit/Km
dN 50 %	-41.79	Nunit/Km
Median rain height	3967.46	m
N0 Wet	26.62	Nunit
Roughness	20	m
Roughness (ITU file)	711.67	m

Fig. 6. ITU values of CDBLA Simulation

geoclimatic factor K and fading data.

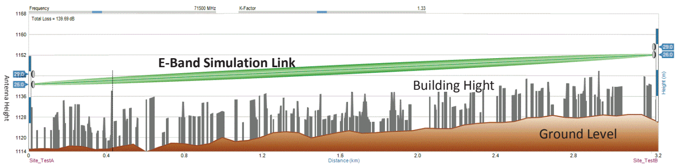
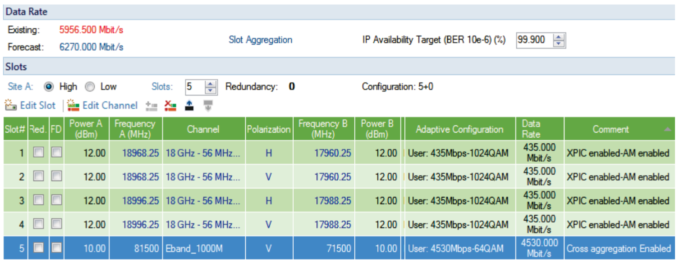


Fig. 7. Schema of Microwave link Simulation

In this simulation, nodes are placed based on a clear Line of Sight (LOS) report, exact on-site coordinates and up to date clutter heights of buildings (Fig.7) that is located in a dense urban area. Fig. 8 are shown for radio parameters to reach 6270 Mbps simulated throughput and 5956 Mbps real throughput. In this configuration 5 slots are used as a 4+0 with XPIC enable for CBM plus 1+0 for E-Band that aggregated together to provide us with enough capacity for 5G small-cells. Other parameters are set according to TableII.

Fig.8 is shown for radio parameters to reach 6270 Mbps simulated throughput and 5956 Mbps real throughput. In this configuration, five slots are used as a 4+0 with XPIC enable for CBM plus 1+0 for E-Band that aggregated together to provide us with enough capacity. Antenna model, Radio configuration (Tx, Modulation, Frequency Channels, etc.) and environmental parameters are set based on TableII, which achieved optimum SLA according to Fig.3. Simulation results are shown in TableIII. In this table, Rain (Annual/Worst Month) displays the unavailability due to rain value, total (Annual/Worst Month) presents the total unavailability value in annual against worst month value and % Time (Annual/Worst Month) displays the unavailability value in annual against worst month value in percentage of the time. BER 10-3, BER 10-6 displays the Bit Error Rates to calculate quality and availability. In this simulation availability of CBM and EBM is 99.999% and 99.9, respectively.



Data Rate

Existing: 5956.500 Mbit/s
Forecast: 6270.000 Mbit/s
Slot Aggregation
IP Availability Target (BER 10e-6) (%) 99.900

Slots

Site A: High Low Slots: 5 Redundancy: 0 Configuration: 5+0
Edit Slot | Edit Channel

Slot#	Red.	FD	Power A (dBm)	Frequency A (MHz)	Channel	Polarization	Frequency B (MHz)	Power B (dBm)	Adaptive Configuration	Data Rate	Comment
1			12.00	18968.25	18 GHz - 56 MHz...	H	17960.25	12.00	User: 435Mbps-1024QAM	435.000 Mbit/s	XPIC enabled-AM enabled
2			12.00	18968.25	18 GHz - 56 MHz...	V	17960.25	12.00	User: 435Mbps-1024QAM	435.000 Mbit/s	XPIC enabled-AM enabled
3			12.00	18996.25	18 GHz - 56 MHz...	H	17988.25	12.00	User: 435Mbps-1024QAM	435.000 Mbit/s	XPIC enabled-AM enabled
4			12.00	18996.25	18 GHz - 56 MHz...	V	17988.25	12.00	User: 435Mbps-1024QAM	435.000 Mbit/s	XPIC enabled-AM enabled
5			10.00	81500	Eband_1000M	V	71500	10.00	User: 4530Mbps-64QAM	4530.000 Mbit/s	Cross aggregation Enabled

Fig. 8. Microwave Radio Simulation Parameters

TABLE III. SIMULATED COMMON BAND AND E-BAND MICROWAVE LINK AVAILABILITY

Slots 4+0 Configuration 1+0 Configuration	Channel - 18 GHz - 56 MHz (Slot No1 - Slot No4)	Rain (Av. % (Std))	Total (Av. % (Std))	% Time
		Annual / Worst Month	Annual / Worst Month	Annual / Worst Month
Channel - 18 GHz - 56 MHz _XPIC (Slot No1 - Slot No4)	**BER 10-3** - 435Mbps-1024QAM	AB: 99.999918 / 99.99920595	AB: 99.99991791 / 99.99920527	AB: 99.99991791 / 99.99920527
	BER 10-6 - 435Mbps-1024QAM	AB: 99.99986056 / 99.99873976	AB: 99.99986042 / 99.99873869	AB: 99.99986042 / 99.99873869
Channel - Eband_1000MHz _V (Slot No5)	**BER 10-3** - 4530Mbps-64QAM	AB: 99.98211882 / 99.91401364	AB: 99.98211858 / 99.91401183	AB: 99.98211858 / 99.91401183
	BER 10-6 - 4530Mbps-64QAM	AB: 99.97968978 / 99.90393692	AB: 99.97968947 / 99.90393456	AB: 99.97968947 / 99.90393456

IV. EXPERIMENTAL RESULTS

In Fig.9 we displayed our three traffic aggregated links for CDBLA, which is implemented on a dense frequency urban 5G small-cell network based on the plan (Fig.1). The implementation contains two of 0.6m, 18GHz Dual Polarized Antenna and one 0.6m E-band Single Polarized Antenna on each side plus Indoor units. The throughput results of CDBLA extracted for sample 10 days shown in Fig10. It depicted that during the traffic peak time when the majority of Internet users are online at the same time, we transferred Ethernet traffic between 5.9∼6.1 Mbps that matched with our simulation results in 19.97mm/h rain rate. Besides, the influence of AM is quite shown, without AM function microwave link dropped completely along with bad weather issues which needs on-site maintenance and much more outage duration time. However, after enabling the AM function, it tries to mitigate the adverse effect of rain attenuation during climate change. With AM enabling, There is a trade-off among modulation size, BER value and throughput. So, we faced with modulation level degradation during fading issues by detecting severe climate situation through analyzing of related alarms. So adaptive modulation enables to guarantee the performance of the traffic and shorten recovery times.
Fig.11,12 show our previous experiments on CBM and EBM links, respectively. Those represent, although the CBM link has stable 1.8 Gbps throughput, it couldn't satisfy the 5G requirements. And for EBM link, even though we reach to the 3.9Gbps throughput, it does not combat to severe weather and couldn't provide a stable 5G Backhaul solution either.

V. CONCLUSION

In the 5G era, traffic to be backhauled increases exponentially, posing significant challenges on 5G backhaul network. So, to meet this broadband backhaul requirements, CDBLA approach introduced and analyzed, based on the exponential growth of traffic data rate. Following our implementation, the practical records provide us with 6.1

Fig. 9. Schema of Microwave link Implementation

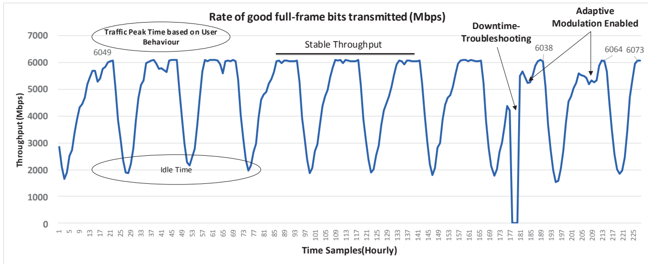


Fig. 10. Real throughput measurement of CDBLA implementation

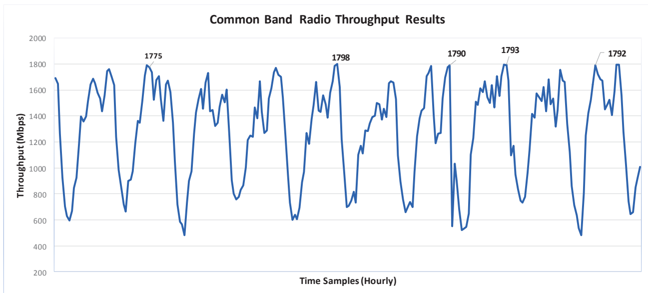


Fig. 11. Common Band 4+0 Configuration Throughput Results-Previous experiment, 1024QAM, BW=56M

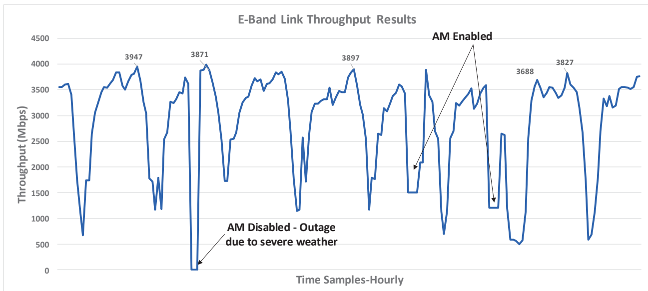


Fig. 12. E-band Band 1+0 Configuration Throughput Results-Previous experiment, 64QAM, BW=1000M

Gbps data rate that satisfies simulation results. As a result, CDBLA could be a perfect solution for 5G small-cells networks in case of throughput, availability, troubleshooting and distance between small-cells to base stations. The comparison of Backhaul technologies presented in TableIV. In this comparison, CDBLA is a optimal (low cost with short time troubleshooting) solution for high capacity microwave links at 5G network.

TABLE IV. COMPARISON OF BACKHAUL TECHNOLOGIES FOR 5G NETWORKS

5G Solution	CBM	E-Band	Optical Fiber	CDBLA
Bandwidth	Small	Medium	Large	Large
Implementation Cost	Low	Low	High	Low
Implementation Period	Short	Short	Long	Short
Troubleshooting Time	Short	Short	Long	Short
Distance	Long $<$100km	Short $<$3km	Long $>$10km	Medium 2$-$5km

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