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Mobile Backhaul in Release 8 and Beyond: Benefits, Challenges, Market Status and Impact Analysis

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Abstract: The significantly increasing mobile capacity demand, the use of advanced techniques like enhanced multiple input multiple output to boost throughput, very high data rate, reliability, very low latency, long battery life, mobility, and to enable internet of things in 4G and 5G technologies, aggravate extreme backhaul requirements with respect to capacity, latency, availability, energy, and on the top of this, cost efficiency. However, it is challenging to get a complete one backhaul technology that can solve all problems of backhaul especially massive introduction of small cells in mind. To overcome various backhaul problems there are many backhaul solutions i.e. the use of diversified backhaul under different use cases provides cost efficient backhaul solution. This paper presents benefits, implementation challenges, and use cases of mobile backhaul in release 8 and beyond. It also presents coverage and capacity analysis using excel based dimensioning tool for a given sample area. Lastly the paper shows economic benefits of diversified backhaul for small and macro cells and high-level implementation strategy for the considered area.

Index Terms: 5G, LTE, LTE-A, Millimetre wave, Mobile backhaul, Small cells, Sub-6 GHz, TVWS.

1. Introduction

The backhaul network in cellular networks can be defined as a transport network that connects base stations to controllers and mobile core network elements. It can also connects the eNBs to other eNBs as far as 4G and beyond technologies are concerned. Mobile backhaul technologies consists currently available dedicated fibre, copper, licensed sub-6 GHz (bellow 6 GHz), unlicensed sub-6 GHz (2.4 GHz, 5.8 GHz), microwave (6-42 GHz), and satellite links [1,2,3,4,5]. In addition, it consists of newly emerging wireless technologies like licensed millimetre wave (70-80 GHz), unlicensed millimetre wave (60 GHz) and TV white space (470-694 MHz) [4,5].

Release 8 and beyond technologies improvement in data rate, capable of supporting multi-traffic volumes, use of advanced techniques like enhanced multiple input multiple output (MIMO) to boost throughput, very high spectral efficiency, reliability, reasonably very low latency, long battery life, mobility, and suitability to enable internet of things (IOT) are factors that play an important role in shifting backhaul architectures from earlier versions like asynchronous transfer mode (ATM), time division multiplexing (TDM) to an all IP model.

IP based backhaul that replaced earlier versions in long term evolution (LTE), long term evolution-advanced (LTE-A) and 5G makes the network management easier and provides a better environment to incorporate IP technologies for routing and quality of experience. With a lot of advancements in LTE, LTE-A and 5G particularly associated with small cells in mind: backhaul is a driving force to use and go further on sub-6GHz, millimeter wave band, TV white space (TVWS) bands, even widely used microwave. Because of very little congestion, millimeter wave bands are possible solution for small cell backhaul. They are very compatible with a short small cell ranges, due to their high frequencies. Similarly, higher microwave frequencies also draw attention to use for small cells backhaul [1,2,3,4,5].

Even though backhaul associated with release 8 and beyond has considerable benefits, there are some implementation challenges. Some of them have been addressed as follows: *Scalability*: to support massive number of base stations at higher capacities the backhaul network must be smoothly scaled [4,5,6]. This is one implementation challenge. *Flexibility*: the introduction of small cells in addition to macro cells in an LTE, LTE-A and 5G environment brings the need to leverage cost-efficient backhaul access infrastructure that can meet required quality of experience. Due to this backhaul access types will be greatly diversified. This in turn drives a requirement for more flexible backhaul solutions. In addition to LTE, LTE-A and 5G, it should support for 2G and 3G services when needed [4,5,6].

Simplicity: to reduce the total cost of ownership (TCO) operations should be simplified. Moreover, it should permit efficient network deployment, administration and maintenance.

This paper addresses: which backhaul technology demand is increasing and which one demand is decreasing i.e. which backhaul technology is intensively or rarely used for small or macro cellular network. It also addresses when and where different backhaul solutions can be used. Coverage and capacity analysis by counting small cells and macro cells for diversified backhaul has been also addressed. Economic benefits using diversified backhaul for small cells and macro cells has been shown. Since there is no one complete backhaul solution that can overcome all backhaul problems, this paper proposed to take the full advantage of diversified backhaul.

The rest of the paper is organized as follows. Section II presents market share of backhaul networks. Section III presents impact analysis of backhaul technology. Section IV, high level implementation strategy, and section V concludes the paper.

2. Market Share

It is well known that market share is an important parameter when measuring the successfulness of backhaul business, and hence it has been introduced as one section of this paper. [1,2,3,4,5,6,7,8,11,12,13,14] shows the usage of macro and small cell backhaul technologies over the couple of years. From the research papers it can be seen that millimeter wave is going to be intensively used for both small and macro cell backhaul worldwide. Also, the demand of fiber for both small cell and macro is increasing due to its unlimited capacity. The macrocell microwave LTE backhaul market will not grow at the same rate as small cell microwave backhaul as it shows consistent growth. Licensed sub-6 GHz for non-light of sight (NLoS) is proved viable small cell backhaul solution [5] [7]. Satellite backhaul technology will remain possible solution, considering some deployments in rural areas where there is no line of sight to macro or other cable infrastructure.

3. Mobile Backhaul Impact Analysis

In this section relevance of mobile backhaul; use cases; and coverage and capacity analysis has been discussed.

3.1 Relevance of mobile backhaul

The significantly increasing data volumes and highly innovative devices will drive the continued need for additional backhaul for mobile operators [8, 9]. To accommodate both access and core network traffic, backhaul network capacity need to be improved. To this end appropriate backhaul technology should be applied in different use cases. The existing usage and deployment strategy of backhaul will not satisfy the desired network requirement of release 8 and beyond [10]. If we use traditional microwave as the only solution it will not provide sufficient capacity because of very narrow channel space. The same will happen if we use sub-6 GHz [8]. The cost of fiber including installation is high even though it has a large bandwidth. The situation is further exacerbated with massive introduction of small cells as the backhaul network is bottleneck for its deployment. These factors are leading mobile operators to use diversified backhaul (as shown in Fig. 1) technologies over conventional backhaul. Thus, diversified backhaul will meet transport capacity requirement as various mobile operators are in a way of commercially launching 5G in 2020.

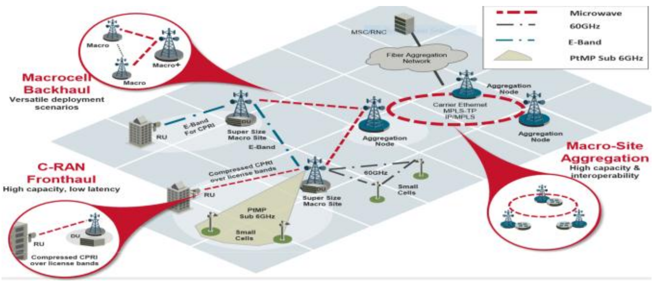

Fig. 1. Diversified backhaul [9]

3.2 Use cases

Use cases can be termed in this document to show where backhaul technologies can be used. Millimetre wave (60GHz) is used to backhaul small cells to street level i.e. street to street or street to rooftop links. Millimetre wave (70-80GHz) is used to aggregate small cells at the rooftop under microcellular sites. Microwave bands is deployed at the point where line of sight to hub is available. Sub-6 GHz (licensed) is deployed to enable the rapid deployment of large areas of small cells. Sub-6 GHz (unlicensed) can be deployed for remote or isolated locations. TVWS can be used as backhaul infrastructure between small cells in locations where TVWS channel availability is high. Satellite can be used for targeted capacity hotspots for locations where there no fiber infrastructure or line of sight to macro. Fiber to cabinet or exchange (FTTX) can be suitable solution for Hotspot, indoor coverage, outdoor coverage where available [6,7,8,11,12,13].

3.3 Coverage and capacity analysis

As a sample an area of $23000m^2$ was taken with total population at peak time approximately 900. This area to be covered with small cells and one microcell using diversified backhaul. For this analysis, excel based dimensioning tool from ALCatel Training LTE with original title: 271545062 –LTE-Rel8-Downlink-RLB-2014-4x4 has been used. From the tool allowed propagation loss and downlink cell range can be obtained and used for coverage and capacity analysis.

DL Link budget for LTE		
eNodeB - UE		
eNB Transmitter characteristics		
Number of PRBs	2	
Downlink data rate	2.00	Mbits/s
eNodeB TX power	46.00	dBm
eNodeB antenna gain	8.00	dBi
eNodeB antenna cable loss	2.00	dB
EIRP	**52.00**	**dBm**
UE receiver characteristics		
UE noise figure	7.00	dB
Thermal noise	-104.43	dB
Receiver noise floor	-97.43	dBm
Required SINR	42.22	dB
Receiver sensitivity	-55.21	dBm
Control channel overhead	1.00	dB
Rx antenna gain	1.00	dB
Body loss	0.00	dB
Shadowing loss	7.00	dB
Interference margin	4.00	dB
Indoor penetration loss	10.00	dB
Allowed propagation loss	**86.21**	**dB**
Boltzmann constant	1.4E-23	

Fig. 2. Allowed propagation loss

Range (Okumura-Hata path loss model)		
Carrier frequency	2600	MHz
BS antenna height	10	m
MS antenna height	2.5	m
MS antenna gain function (large city)	1.92587	
MS antenna gain function (small city)	3.11382	
MS antenna gain function (suburban)	16.2584	
MS antenna gain function (rural)	37.2644	
Path loss exponent	38.35	
Path loss constant (large city)	146.322	dB
Path loss constant (small city)	145.134	dB
Path loss constant (suburban area)	131.989	dB
Path loss constant (rural area)	110.983	dB
Path loss constant (rural Saarijarvi)	120.983	dB
Downlink range		
Urban city	**0.03**	**km**
Small city	**0.03**	**km**
Suburban	**0.06**	**km**
Rural	**0.23**	**km**

Fig. 3. Downlink cell range

For coverage analysis, the range (radius) is 30m from Okumura-Hata path loss model. Area of a single cell can be calculated using (1):

$$A = \frac{3}{2} N R^2 \sqrt{3} \tag{1}$$

where:
A = Area
R = Radius of the cell
N = Cluster size
R= 30m

Area of single cell (1) = 2338.2m^2 and Total area = 23000m^2. Then the required number of base stations to cover area can be total area divided by single cell area which is 10.

For capacity analysis, assuming 90% of the total population is covered: 0.9*900= 810. Assuming Overbooking factor of 50. Then simultaneously supported users to be

$$^{810}/_{50} = 17$$

Assuming 3 small cell users supported by one small cell

$$\frac{17}{3} = 6$$

The number of base stations for capacity is 6 and which is less than base stations for coverage. This shows capacity can be effectively handled.

4. Economic Benefits

It has been shown using the following simple layout how network to be backhauled to show economic benefits of given area. Two scenarios have been considered to show economic benefits of diversified backhaul in the sample area. The first: assuming macro cell to aggregation point2 is fiber and remaining links are point to point (PtP) microwave.

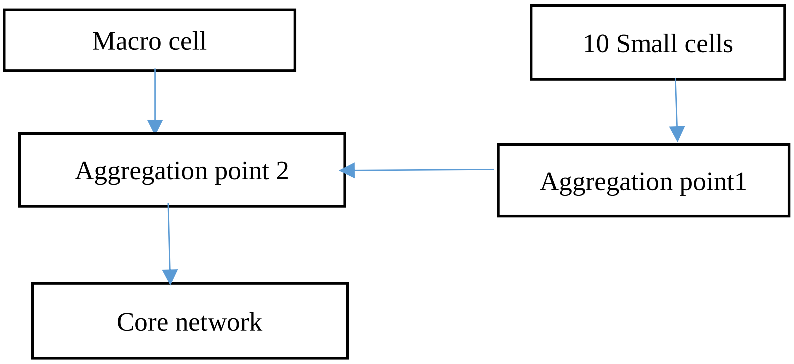

Fig. 4. Sample backhaul network layout

The second: assuming macro cell and aggregation point2 backhauled by licensed millimetre wave band PTP and aggregation point 2 and core network backhauled by PTP microwave and rest is backhauled by point to multipoint (PTMP) microwave.

Table 1. Scenario 1

Capex of fiber	Cost (USD)
Equipment cost: connection setup	2000
Network planning, site acquisition, installation	2000 (RAN site)
Opex of fiber	
leased line fees (per year)	140,000
Other recurring operating costs (power, maintenance, etc.)	1000 (RAN site)
Total cost of fiber at 5 years = 2000+ 2000+ 140,000*5 +1000 = USD 705000	
Capex of PTP MW	
Equipment costs, outdoor per link	11500
Equipment costs, indoor	9000
Network planning, site acquisition, installation per link	8700
Opex of PTP MW	
Site rental fees (per year): Outdoor equipment and indoor equipment respectively	7000 per link, 1500 per link
Spectrum licensing fees	5418 per link (14 MHZ link)
Other recurring operating costs (power, maintenance, etc.)	8000 per link

Total cost for PTP MW at 5 years = 11500*10+ 9000+8700+7000*1*5+1500*10*5+5418*11+8000*11 = 390298 USD. Then total cost of fiber + PTP MW at 5years = 390298 + 705000 = 1095298 USD

Table 2. Scenario 2

Capex of licensed millimeter wave band PTP	Cost (USD)
Equipment costs, outdoor per link	19500
Equipment costs, indoor	9000
Network planning, site acquisition, installation per link	8700
Opex of licensed millimetre wave band PTM	
Site rental fees (per year): Outdoor equipment and indoor equipment respectively	7000 per link, 1500 per link
Spectrum licensing fees per link per year	81
Other recurring operating costs (power, maintenance, etc.) per link	8000
Total cost of millimetre wave band at 5 years = 88105 USD	
Capex of PTP MW	
Equipment costs, outdoor per link	11500
Equipment costs, indoor	9000
Network planning, site acquisition, installation per link	8700
Opex of PTP MW	
Spectrum licensing fees (56 MHZ link)	21672 per link
Site rental fees (per year): Outdoor equipment and indoor equipment respectively	7000 per link, 1500 per link
Other recurring operating costs (power, maintenance, etc.)	8000 per link
Total cost of PTP MW at 5 years = 101372 USD	
Capex of PTMP MW	
Equipment costs, outdoor per AP and per terminal resp	11900, 4170
Equipment costs, indoor	9000
Network planning, site acquisition, installation per hub and Ran site resp	5950, 3650
Opex of PTMP MW	
Site rental fees (per year): Outdoor equipment (AP, terminal) and indoor equipment (AP, terminal) resp	(4000, 3000), (1000,500)
Spectrum licensing fees (56 MHZ link)	840
Other recurring operating costs (power, maintenance, etc.) per RAN and hub site resp	4000, 4000
Total cost of PTMP MW at 5 years = 250060 USD	
Total cost of PTP MW + PTMP MW + Millimeter wave band PTP at 5 years = 439537 USD	

AS it can be seen from the total cost, the first scenario costs 1.09 million USD and second costs 0.44 million USD. This reveals that if we diversify backhaul technologies more and select appropriate one will lead cost efficient backhaul network.

5. High Level Implementation Strategy

High level implementation strategy of backhaul network for given area can be shown in tabular form as follows

Table 3. High level implementation strategy

	Year 2021			Year 2022		
	1-4	5-8	9-12	1-4	5-8	9-12
Site survey	X					
Conduct backhaul market analysis		X				
Develop backhaul deployment strategy			X			
Dimensioning				X		
Detailed planning					X	
Deploy backhaul network						X

January- April (1-4), May-August (5-8) and September-December (9-12)

6. Conclusion

It is very important to upgrade the performance of backhaul network as 4G and 5G technologies requires very low latency, very high data rate, and reliability. All IP backhaul simplifies management, results cost savings and easier maintenance. Challenges associated with backhaul enhanced the stake holders to go further on emerging wireless technologies to get additional backhaul. The market status of emerging wireless technologies like millimetre wave shows promising future solution for backhaul as it has been shown in aforementioned review materials. Since there is no one complete backhaul solution that can overcome all backhaul problems, diversified backhaul in this research has been proposed as cost efficient solution that helps to meet high transport requirement capacity. To this end, it has been estimated based on OFCOM and Senza report that backhaul capex and opex for two scenarios for given site to show cost efficiency of diversified backhaul. The cost estimation shows that more diversified and appropriate backhaul technology will give most cost-efficient solution.

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