White Paper

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Wireless Backhaul Challenging Large-Capacity and High-Speed Transfers

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1. Introduction

Mobile data traffic is continually increasing. Cisco Systems reported in *Cisco Visual Networking Index 2015* that worldwide mobile device connections totaled 7.4 billion in 2014 and are expected to see a 10-fold increase in traffic between 2014 and 2019.

Under these circumstances, not only are new technologies required for connecting between mobile devices and base stations, but also increases in the speed and capacity of the supporting backhaul are required too. To achieve this, mobile backhaul systems using wireless (hereafter wireless backhaul) are implementing solutions using modulation multiplexing and band-widening technologies.

This document describes the issues for backhaul wireless units used by large-capacity and high-speed microwave and millimeter-wave communications.

2. Outline of Mobile Backhaul

Mobile terminals connect with base stations to communicate with other mobiles or servers. The base stations transfer the mobile communications data to the core network. Data from multiple base stations distributed throughout the communications area is transferred by a network of mobile communications systems that collect and transfer the data using various exchanges; this is called the "Mobile Backhaul".

Communications between mobile backhaul locations uses both wired and wireless technologies for the Physical layer/hardware interfaces. Wired technologies use either copper cables or optical fibers, but optical fibers are more commonly used recently. Optical fiber has a larger traffic capacity than wireless and also features stable communications quality, but sometimes suffers from installation issues due to difficult geography and economic issues. On the other hand, while wireless communications are inferior to optical fiber in terms of capacity and stability, they are better in terms of easier and faster installation as well as lower cost. In addition, wireless has advantages during disasters and can extend and supplement wired. Japan, Korea, and China have installed optical fiber extensively, while wireless is used widely in other parts of Asia, Europe, Middle East, Africa and especially NIEs for both reasons of cost and early deployment of mobile services.

General explanation of mobile backhaul technologies covers wired and wireless as well as data link and multiple access methods. There are circuit switched based on conventional telephone networks, Time-Division Multiplexing (TDM), and Ethernet based on packet switching. In recent years, there has been a shift in mobile to LTE supporting only packet communications, so packet-based Ethernet is being more widely adopted by mobile backhaul (there are also hybrid TDM/Ethernet systems too). Support for TDM, which maintains continuity with legacy GSM and W-CDMA services, will not disappear in the foreseeable future.

To summarize, mobile backhaul interfaces can be chosen as follows and are chosen according to the usage, installation environment, and carrier/regional strategy.

(1) Wired • TDM
(2) Wired • Ethernet
(3) Wireless • TDM
(4) Wireless • Ethernet

The term "Mobile Fronthaul" is also used as part of the vocabulary related to mobile backhaul. Generally, it describes the combination of the Base Band Unit (BBU) handling baseband signalling and control of the Remote Radio Head (RRH), the RRH with wireless TRx sections, the Remote Radio Unit (RRU), and the associated combination of antennas. The mobile backhaul is the network structure linking the BBU to the Core network, whereas the mobile fronthaul is the structure linking the BBU and RRH. Currently, optical fiber is mainly used for the interface between the BBU and RRH; connection is made using the CPRI (Common Public Radio Interface) and OBSAI (Open Base Station Architecture Initiative) protocols.

The background leading to the concept of mobile fronthaul has been the investigation and introduction of a new mobile network architecture called Centralized Radio Access Network (C-RAN). In C-RAN, the BBUs of multiple base stations are centralized at one location and the base station is only the RRH and antennas. Using this type of centralized control configuration, supports precise complex control, such as interference control between multiple RRH/small cells (small base stations), and coordinated communications. Using this method supports use of optical fiber for the mobile fronthaul as well as optimized wireless installation and operating costs.



Fig. 2-1 Mobile Backhaul Concept

3. Wireless Backhaul Technologies

3.1 Equipment Configuration

The wireless backhaul uses a fixed Point-to-Point (PTP) wireless system in the microwave or millimeter wave bands with a structure rather like the conventional telephone and broadcast wireless repeater systems. Two-way communications are performed by two identical facing wireless communications systems. There are two technologies: FDD and TDD, but FDD in the micro/millimeter wave band is most common. In the millimeter wave band, wireless propagation characteristics vary greatly with atmospheric conditions, and the Rx sensitivity between equipment, the communications quality, the temperature and humidity, etc., are monitored, and the Tx power and modulation method are changed accordingly to optimize communications conditions under the control.

The wireless backhaul equipment is composed of an Out Door Unit (ODU) located out of doors and an In Door Unit (IDU) located indoors. The antenna is connected to the ODU. The ODU houses the wireless transmitter and receiver units. It converts received micro/millimeter wave signals to Intermediate Frequency (IF) data signals and conversely converts IF data signals for sending to micro/millimeter wave signals. A coaxial cable connects the ODU and IDU and carries the data signals, ODU control signals, power, etc. The IDU is connected to the network and handles sending/receiving of IF data to/from the ODU as well as STM/packet conversion for TDM (SDH)/Ethernet data transmission. The IDU can have multiple attached network interfaces supporting STM-x, 1000Base-SX/TX, etc.



Fig. 3-1 Wireless Backhaul Configuration

Recently, the BBU has been reduced in size by limiting the network interfaces to Ethernet, and the ODU and IDU have been integrated into a compact package. These smaller units are being proposed for short-range, line-of-sight (LOS) applications using the V-band (60 GHz) and E-band (70 to 80 GHz) with good linearity. They are expected to find applications in mobile fronthaul.

3.2 Frequency Bands

In this report, the frequency band from 3 GHz to 30 GHz (wavelength of 1 to 10 cm) is called the microwave band, and the frequency band from 30 GHz to 300 GHz (wavelength of 1 mm to 10 cm) is called the millimeter wave band. Figure 3-2 shows the frequency bands allocated to wireless backhaul applications.



Fig. 3-2 World Backhaul Spectrum Allocation (Source: GSMA Wireless Backhaul Spectrum Policy Recommendations & Analysis Oct.2014 / ABI Research)

Conventionally, most of the allocated frequency bands are below 38 GHz. More recently, the 60-GHz and 70 to 80-GHz bands have been allocated for use to secure a wider bandwidth for implementing larger-capacity and faster transfers. Since the actual frequency bands and applications depend on national laws governing radio, not all bands are available in all regions.

The micro/millimeter wave band is characterized by strong straightness, but signals are easily attenuated by oxygen and rain (Fig. 3-3). The attenuation is especially large near 60 GHz. As a consequence, frequencies below 10 GHz are commonly used for long-range propagation distances between 10 and 200 km.



Fig. 3-3 Frequency and Attenuation by Oxygen and Rain (Source: GSMA Wireless Backhaul Spectrum Policy Recommendations & Analysis October 2014)

<u>6 GHz to 42 GHz Band</u>

Frequency bands below the 42-GHz band (40.5 - 43.5 GHz) are licensed bands. The channel bandwidth is between 3.5 MHz and 112 MHz. The propagation speed is theoretically about 1 Gbps when using a bandwidth of 112 MHz and 2048QAM; this is the index for maximum transmission capacity using this frequency band.

<u>60 GHz (V-Band)</u>

The 60-GHz called V-band is used in Japan and Europe (57 to 66 GHz), North America, Canada, and Korea (57 to 64 GHz). Allocated bandwidth is wide about 7 to 9 GHz offers the possibility of achieving propagation speeds of better than 7 Gbps. Additionally, this band does not require an operating license (unlicensed band) and the lower operating costs make it a focus of current interest.

Since the 60-GHz band suffers large attenuation by oxygen and rain, it is used mainly for short-range, large-capacity applications, such as backhaul/fronthaul for small cells. In addition, it is also used for information appliances, such as wireless HD, HDMI, IEEE802.11ad, WiGig, etc., requiring large-content transfers, and for radar; these applications require interference control, such as channel/bandwidth dynamic allotment, power control, etc.

The EU ETSI EN 300 408 standard covering 58-GHz band PTP digital wireless systems specifies a channel spacing of either 50 MHz or 100 MHz. Moreover, ECC Recommendation (09)01 and (05)02 for fixed PTP wireless systems defines channel bandwidths as multiples of 50 MHz. Channel bundles are used to secure a wide bandwidth.

70/80 GHz (E-band)

A wider bandwidth than the 60-GHz band is the licensed E-band covering 70 to 80 GHz (71 to 76 GHz, and 81 to 86 GHz). The E-band has better carrier linearity than the V-band and is less attenuated by oxygen and rain. ECC Recommendation 05(07) specifies a channel configuration from 250 MHz to 4750 MHz. Both FDD and TDD technologies can be easily implemented, supporting both 2.5-GHz bidirectional, and 10-GHz speeds.





3.3 Modulation Methods

Quadrature Amplitude Modulation (QAM) is the most commonly used as modulation method. Any of various modulation methods, such as QPSK, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, etc., can be chosen as the best modulation, depending on the propagation conditions, such as rainfall conditions. Using the wider E-band, it is possible to achieve a theoretical best-effort speed of 10 Gbps with a bandwidth of 5 GHz and 16QAM.

Table 3-1 Relationship Between Theoretical Bandwidth and Maximum Capacity

(Source: Wen Wu, "A FPGA-based 5 Gbit/s D-QPSK Modem" /

Bandwidth		2.5 GHz	5 GHz	10 GHz
Max. Capacity [Gbps]	BPSK	1.25	2.5	5
	QPSK	2.5	5	10
	16QAM	5	10	20

Carlos Salema. "Microwave Radio Links: From Theory to Design", Wiley 2003)

4. Issues in Wireless Technologies

for Implementing Large-Capacity and High-Speed Transfers

Higher-order modulation methods (multiplexing) and use of wider bandwidths are two approaches now being used to increase transmission capacity/speed. However, there are some technical issues to solve.

Using higher-order modulations increases the Peak to Average Power Ratio (PAPR), but the amplifier distortion and non-linearity characteristics are adversely affected frequently. In addition, the Signal to Noise Ratio (SNR) requirement is increased and symbol errors occur easily. The 3-dB sensitivity drops with each increase in the modulation order. As a result, implementation of higher-order modulations requires a wireless unit with a low intrinsic phase noise and low noise figure (NF).



Fig. 4-1 Higher Order Modulation Issues

It is difficult to use a higher-order modulation with a wider modulation bandwidth due to the reduced SNR, so a relatively lower-order modulation, such as QPSK, is used. As a result, transfers use an extremely fast sampling rate and the phase noise and Jitter characteristics become key elements in transmission quality.

Millimeter wave bands such as the V-band and E-band are used to assure wider bandwidths. Currently, many millimeter wave band transmitters and receivers use a multiplier with the VCO and PLL signals to achieve a high LO frequency. Generally, since the phase noise added to the LO signal is determined by the multiplication rate, the LO signal source requires a phase noise performance several times better than the phase noise performance determined by the output/Rx frequency. (For simple calculation, just add 20Log(multiplication rate). For example, add 18 dB at 8 times multiplication). Similarly, high phase performance is required for the millimeter wave band even using an on-chip high-frequency oscillator.

5. Microwave/Millimeter Wave Wireless Unit Measurement Points

5.1 Basic Blocks of Wireless Unit

The wireless backhaul ODU accepts input of the Tx IF signal from the IDU, up-converts it to the corresponding micro/millimeter wave frequency signal and outputs it. In addition, it down-converts the micro/millimeter wave frequency signal received from the antenna to an IF signal and outputs it to the IDU. The IF signal is nearly always a common frequency so it can be used irrespective of the ODU maker.

The Tx unit up-converts the input IF signal to the micro/millimeter wave frequency signal by mixing with the LO signal using a mixer. After the filter at the next stage removes unwanted frequencies, the signal is output at the antenna. The Rx unit amplifies the signal received from the antenna using a low-noise amplifier (LNA) before down-conversion to the LOF signal by mixing with the LO signal.



Fig. 5-1 Basic Blocks of ODU

The LO signal frequency is selected according to the Tx and Rx frequencies. It is generated by the VCO and PLL. Up-conversion and down-conversion for high frequencies requires a higher LO signal, which is provided by multiplying at passage through a multiplier. The wireless unit phase noise performance is determined by the phase noise performance of this VCO + PLL and multiplier.

In the hope of cutting costs, some parts of the VCO and PLL circuits may be shared irrespective of the Tx and Rx frequencies. As a result, the multiplier type and multiplication rate are chosen and adjusted according to the Tx and Rx frequencies. Since phase noise increases as multiplication rate increases, shared parts should be used as far as possible by setting the performance of the VCO and PLL circuits for higher Tx and Rx frequency products.

5.2 Phase Noise Measurement using Spectrum Analyzer

Phase noise can be measured with a spectrum analyzer. To measure low phase noise, a spectrum analyzer must be selected with sufficiently lower phase noise than the phase noise of the wireless unit to be measured. For example, the impact of the measuring instrument on the measurement result is 0.4 dB when the phase noise performance of the wireless unit is -90 dBc/Hz and the spectrum analyzer has a performance of -100 dBc/Hz with a margin of 10 dB. Generally, spectrum analyzers with good phase noise performance tend to be extremely expensive. Since wireless units must be developed and evaluated over short time periods and a lot of performance data must be collected to assure reliability, it is necessary to have sufficiently good measuring instruments. In particular, if one spectrum analyzer can be used for wireless backhaul evaluation covering an extremely wide frequency range from 6 GHz to 80 GHz, it would greatly increase work efficiency as well as assure consistent measurement results. Consequently, a key point is selection of a spectrum analyzer with the required phase noise performance and a 10-kHz and 100-kHz offset from the center frequency.



Fig. 5-2 Example of Phase Noise Measurement using Spectrum Analyzer (Sweep Function)

5.3 Using Phase Noise Measurement Function

Some spectrum analyzers offer dedicated phase noise performance measurement functions and software. The phase noise measurement function displays the frequency offset from the center frequency on the x-axis versus power density on the y-axis. It is relatively simple to operate compared to measurement using common sweep-type spectrum analyzers. In addition, the sweep-function display the result combining amplitude noise and phase noise, however, the phase-noise function can display only the phase noise using signal processing from digitized data.



Fig. 5-3 Example of Measurement Using Phase Noise Measurement Function

5.4 Importance of Measurement System Noise Floor in Millimeter Wave Band

When measuring spectrum of high-frequency, wideband signals, in addition to phase noise, the noise floor/DANL (Display Average Noise Level) of the measurement system is very important. The noise floor is expressed as the power of the normalized signal per Hz. The power per Hz is lower for a wideband signal of the same power. For example, at a bandwidth of 2 GHz, for a signal with a total power of -20 dBm, the noise floor is -20 - 10 Log(2,000,000,000) = -103 dBm/Hz. To measure this signal, the noise floor of the measurement system itself must be lower than this value. Recently, some spectrum analyzers have been developed that can measure frequencies above 50 GHz without using an external mixer, but this noise floor performance requirement remains an issue.





(Left: Example using Anritsu High-Performance Mixer; Right: Example using General Harmonic Mixer)

At wireless backhaul spectrum mask tests, the measurement dynamic range is important for the limit of mask test that it is -45 dB from the signal level. In the millimeter wave, the dynamic range performance is specified as the difference between the P1dB performance and the noise floor performance. As an example, when the P1dB performance is 0 dBm, a -10 dBm signal can be input as the total power because it has a margin of 10 dB to avoid the influence of level compression. When the signal bandwidth is 2 GHz, the signal level becomes -103 dBm/Hz. The noise floor performance required by the spectrum mask test is -148 dBm/Hz, so the required measurement system dynamic range is 0 dBm -(-148 dBm) = 148 dB.

Conversely, when there is the instrument with P1dB is 0 dBm and the noise floor is -150 dBm/Hz, the spectrum mask test can be executed with a dynamic range performance of 150 dB. However, the impact of the measurement system on the measurement results is 2.2 dB and the level error of measurement system increases. The use of pre-amplifier is normal to improve the noise floor performance, but the pre-amplifier deteriorates P1dB performance, so the dynamic range becomes narrow. Therefore, the use of Noise Floor Reduction function is effective to expand the dynamic range while maintaining P1dB performance. Noise Floor Reduction function subtracts the previously measured internal-noise components of the measurement system from the measurement and displays the result. The reduction effect is in the range of 7 to 11 dB. In this example, the dynamic range performance becomes 150 dB + 11 dB = 161 dB, and the impact of the measurement system becomes just 0.22 dB.

It is important to choose a spectrum analyzer with a wider dynamic range in order to do a spectrum mask test with less error.



Fig. 5-4-2 Example of Noise Floor Reduction Function of MS2840A

5.5 Points When Selecting External Mixer

Frequencies exceeding the upper frequency of the spectrum analyzer can be measured by using an external mixer. Spectrum analyzers for micro/millimeter wave band measurements supporting an external mixer output a LO signal tuned to the measurement frequency and have a coaxial port for inputting the signal that has been converted to IF by the external mixer.



Fig. 5-5 Microwave/Millimeter Wave Measurements Using External Mixer and Spectrum Analyzer

Use of an external mixer causes loss due to frequency conversion. The noise floor rises if this conversion loss is large. Moreover, at measurement using an external mixer, since there is no attenuator after the spectrum analyzer IF input, the input level must be tuned by inserting an attenuator in front of the external mixer. It is necessary to reduce input signal level with the attenuator to avoid deviation of measurement in case of modulated signal, to adjust permitted level of the external mixer in case of CW signal. That can be an additional factor in raising the noise floor.

Consequently, measurement of high-frequency, wideband signals requires selection of both a spectrum analyzer and external mixer with sufficient performance margins.

6. Summary

Mobile data traffic continues to increase and mobile backhaul and wireless backhaul systems require fast transmission speeds exceeding 1 Gbps to cope with increased traffic. Consequently, investigation and introduction of multiplexed modulation technologies and wider bandwidths is being promoted, making the phase noise performance of wireless units a key issue. In selecting measurement systems, it is important to strike the right balance between systems with sufficient performance margins for phase noise and noise floor measurements, applicability to various frequency bands, and introduction and operation costs.

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