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Cellular backhaul technologies

MOBILE backhaul is a term commonly used to describe connectivity between base stations (BT) and base station controllers (BSC)/radio network controllers (RNC) in cellular systems over a variety of transport media. According to an estimate, 25% of total Mobile Network cost is in transport, of which 75% is spent on backhaul and about 50% of the network operational cost is in broadband. Today backhaul relies mostly on copper, optical fiber and microwave radio links. Increasing bandwidth requirements, change in type of traffic transported, requirement of QoS based prioritisation and high cost of legacy backhaul necessitate new solutions. Some of the promising solutions use packet switched networks and wireless technologies that offer attractive features with respect to low cost and availability. However, migration to new technologies raises new technical challenges related to QoS, packet efficiency and timing synchronization. Also, the "all-IP" trends in 4G networks are of current research interest for wireless backhaul. Traditional and emerging technologies for backhaul are briefly described here.

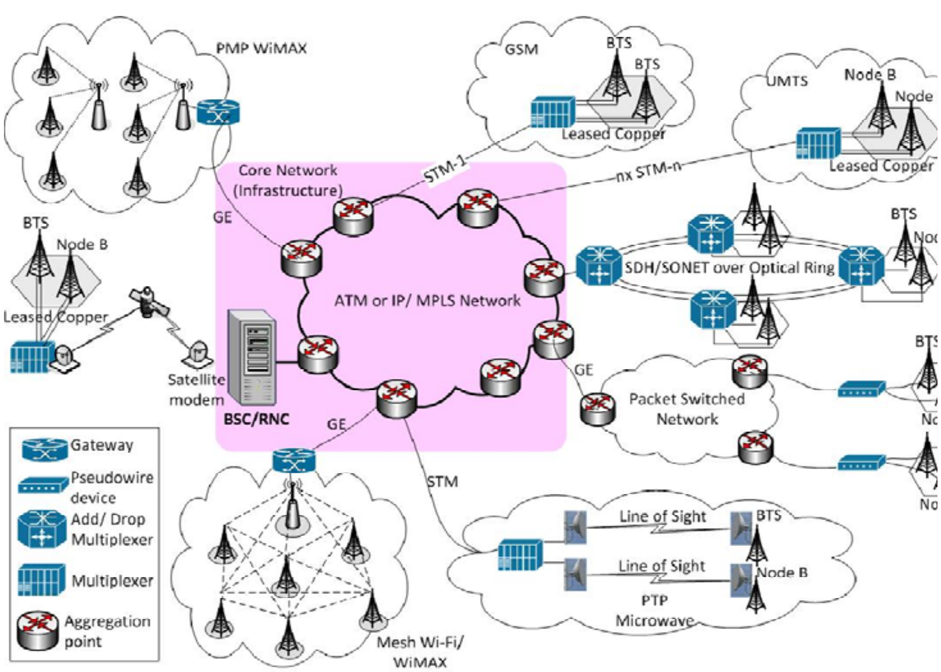


Figure: Traditional and emerging cellular backhaul technologies[1]

Copper

Copper cables are the traditional backhaul medium. TDM techniques using Plesiochronous Digital Hierarchy (PDH) are prevalent techniques which allow

In this issue

Did you know this about femtocells?

Femtocells are low-power access points, providing wireless voice and broadband services to customers in home or at office. With some service providers consistently facing congestion, femtocells are a useful way to make customers happy by improving indoor cell coverage, while easing traffic on base transceiver stations and backhaul. Current designs typically support 2 to 4 active residential mobile phones and 8 to 16 active mobile phones in enterprise settings. They provide a "5 bar" coverage when there is no existing signal or poor coverage from a macrocell and allow macro to femtocell handoff when the user arrives home. Femtocells operate at very low transmit powers, radiating less than 0.1 watts and, more usually, well below 0.02 watts. They also allow mobile phones to work at very low powers, increasing their battery life, reducing interference and any possible radiation hazards.

One of the questions that often gets asked is “What about the backhaul issues?” Femtocells backhaul their data over standard residential broadband connections, including DSL and cable, using standard Internet protocols. This may be over a specific Internet service provider’s network, over the Internet itself or over a dedicated link. However, since the femtocells connects to the subscriber's broadband connection, voice and multimedia traffic traverse the Internet -- and the mobile service provider avoids a significant portion of the expense for backhaul.

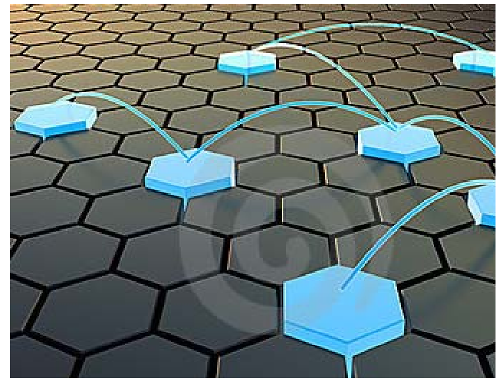
multiplexing multiple voice channels from base stations and transporting them to the BSC in different time slots. When traffic grows and TDM does not suffice then Ethernet or xDSL technologies (e.g. G.SHDSL, VDSL2) are often used on copper to deliver the required bandwidth. For better bandwidth utilization, voice compression techniques such as G.729 and EVRC have been introduced to compress 64 kbit/s PCM encoded voice streams, leading to a throughput gain of four folds. One E1 can support 30x4 = 120 voice calls.

Fiber

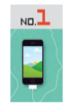
Solutions on fiber would range from point to point fiber optic links, Synchronous Digital Hierarchy (SDH) rings and variants of Passive Optical Network (PON) technology, *Gigabit PON*[GPON], *Ethernet PON* [EPON]. Optical fibers may be deployed in dense urban and suburban locations, which are considered high traffic areas. In many cases the existing access and access-aggregation may be used for backhauling mobile traffic. E1 copper lines from multiple sites may be multiplexed into higher rate optical streams like STM-16 (2.4 Gbit/s). The use of SDH rings can be decided based on parameters like distance between the cell site and the add/drop multiplexer, the number of E1 connections per site and the number of cell sites to be connected via the fiber ring. Results[1] indicate that a ring should at least serve 4 cell sites to achieve 27% or more cost savings.

Microwave and Satellite Wireless Backhaul

Microwave radio and satellite links are utilized in locations where wired backhauls are difficult to deploy. Microwave transmission can be carried out in various frequency bands including licensed (6 GHz to 38 GHz) and unlicensed (2.4 GHz and 5.8 GHz) bands. Using unlicensed bands can reduce Capital Expense (CAPEX) but raises radio interference issues. The used frequency spectrum affects bandwidth capacity and distance coverage; the higher the frequency, the greater the bandwidth capacity and the shorter the coverage range. In all cases, the presence of Line of Sight (LOS) between cell sites and aggregation points is required and hence microwave is limited to short distance transmission when used in metropolitan environments. However, in rural environments, when a LOS is present, microwave transmission can be quickly installed to cover long distances. Compared to E1 copper links, implementing microwave links results in higher CAPEX, however, they are likely to incur less OPEX over time. Microwave can be implemented in the Point-to-Point (PTP), Point-to-Multipoint (PMP), or proprietary multihop configurations for better coverage. Deploying PMP topology in microwave backhaul network can only be cost efficient if at least 5 cells are served by each PMP system[1]. The digital transmission technique over microwave links can be based on PDH, SDH or Ethernet (GE protocol). On the other hand, satellite offers solution for locations where no other backhaul technology is feasible. The transmission is based on E1 techniques. Typical propagation delays for satellite are 270ms plus processing delay which are higher than 250 ms limit for voice services. These links are more expensive but, to take care of the cost, DAMA techniques are used.



Top 11 Technologies of the decade (2000-2010)*


Smartphones: The Pocketable PC
Is your phone smarter than a fifth grader?


Social Networking: Friended
Bandwidth, digital cameras, and a hunger for connectedness have created a virtual dinner party


Voice Over IP: Setting Phone Service Free
How Ma Bell's cash cow became a free software app


LED Lighting: Blue + Yellow = White
Giving LEDs the blues was the key to replacing the incandescent bulb


Multicore CPUs: Processor Proliferation
From multicore to many-core to hard-to-describe-in-a-single-word cores


Cloud Computing: It's Always Sunny in the Cloud
Cloud computing puts your desktop wherever you want it


Drone Aircraft: How the Drones Got Their Stingers
Unmanned aerial vehicles come of age


Planetary Rovers: Are We Alone?
Planetary rovers attempt to answer the most profound question in science


Flexible AC Transmission: The FACTS Machine
Flexible power electronics will make the smart grid smart

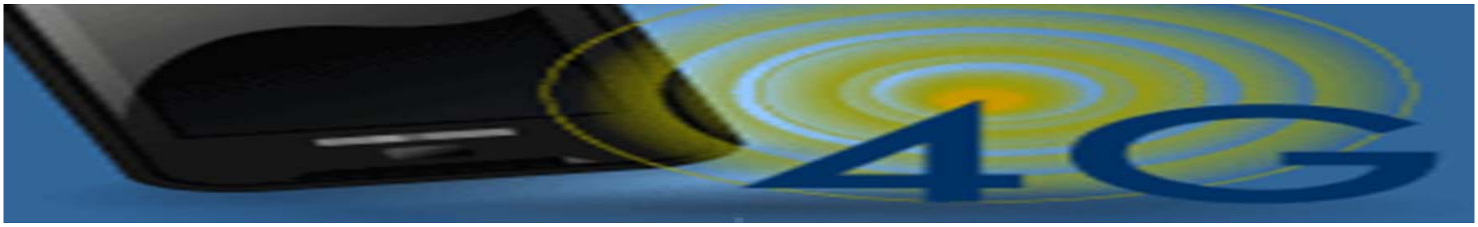

Digital Photography: The Power of Pixels
Digital photography changed not only how we take pictures but also how we communicate


Class-D Audio: The Power and the Glory
A quiet revolution is transforming audio electronics

Source: IEEE Survey

The Pseudowire Framework

As the next generation LTE systems, and the like, are expected to natively use packet-based backhauls, the Pseudowire framework was introduced as a backhaul technology to transport traditional services, e.g. TDM over packet switched networks, e.g. Ethernet, IP or MPLS. The mechanism of transporting TDM traffic over a packet switched network is referred



to as *circuit emulation* or "TDM Pseudowire". It is widely accepted that Pseudowire techniques offer significantly lower cost per megabit, with a cost/megabit ratio for a E1 circuit to Ethernet of approximately 6 to 1[3]. Several standards have been published by the IETF, such as RFC 5086 and RFC 5087 which address circuit emulation for GSM backhaul; Many Pseudowire standards have been recently published by the IETF Pseudowire Emulation Edge to Edge (PWE3). Although migrating to packet switched networks for cellular backhaul offers significant advantages, it poses technical issues relevant to timing synchronization, quality of service (QoS), and packet efficiency. QoS issues arise as packet switched networks are predominantly best-effort and connection-less, which make them difficult to offer QoS guarantees. With the inception of MPLS RSVP-TE as a connection-oriented switching paradigm, it became possible to offer end-to-end QoS with fast packet delivery. Packet efficiency arises as large protocol overheads are added to the service payload. It is a serious problem for data packets with low payloads (e.g., voice) where the packet header size is comparable to the payload size. In order to mitigate this issue, header reduction techniques have been proposed. In addition, IETF standards widely addressed efficiency issues for VoIP traffic (e.g., RFC 2507, RFC 2508, and RFC 3095 Robust Header Compression (ROHC)). For example, RFC 2508 reduces the 40 bytes RTP/UDP/IP header to 2 bytes while ROHC reduces it to 1 byte. Pseudowire can handle out-of-order arrivals by either dropping the out-of-order packets or by re-sequencing the packets into the correct order when possible. For packet loss issues, Pseudowire has a frame loss detection feature that enables the receiving end to recognize losses by tracking the sequence number of the received packets.

Wi-Fi Network Technology

Wireless Fidelity (Wi-Fi) was originally designed for indoor usage based on the IEEE 802.11 standards and operates in the 5 GHz and 2.4 GHz unlicensed bands. Recent research advances in industry and academia demonstrated the feasibility of long distance Wi-Fi connectivity up to 38 km[1]. This has been an active area of experimental research. Wi-Fi can be an attractive low cost solution for backhaul which can substitute microwave links. Wi-Fi links can be used in combination with Pseudowire to backhaul traffic from nearby cell sites to the radio network controller residing in the core network. Although Wi-Fi technology offers attractive cost benefits and deployment flexibility for backhaul networks, it poses design issues relevant to the achieved throughput, distance coverage, packet overhead, and timing and synchronization. For throughput there are proprietary extensions to 802.11 that support upto 108 Mbps[1]. The IEEE 802.11n standard improves the throughput to 600 Mbps using MIMO. Frequency reuse can be used so that Wi-Fi channels are used is sufficiently separated communicating groups. In addition, several vendors offer 802.11 commercial products to provide long distance outdoor coverage with proprietary modification of MAC protocol. At the MAC layer many parameter values are not suitable for outdoor scenarios e.g ack timeout, contention window and round trip time. Packet efficiency is taken care of by using concatenation techniques as well as header compression techniques. The IEEE 802.11e amendment was introduced to support QoS on Wi-Fi networks.

WiMAX Network Technology

Wireless interoperability for Microwave Access *(WiMAX)* was originally designed for outdoor usage and is defined in the IEEE 802.16 standards for broadband wireless technologies. WiMAX is based on OFDM and provides higher throughput and longer coverage range compared to Wi-Fi. WiMAX supports a maximum range of approximately 50 km for single-hop architectures under of line of sight conditions and 25 km in non-line of sight connectivity scenarios[1]. It can operate in both unlicensed (typically 2.4 GHz and 5.8 GHz) and licensed (typically 700 MHz, 2.3 GHz, 2.5 GHz, and 3.5 GHz) bands. Backhaul applications can use the relatively simple 802.16-2004 standard for fixed connectivity applications, in point-to-point, point-to-multipoint, and mesh topologies. Theoretically, WiMAX can provide single channel data rates up to 75 Mbit/s and up to 350 Mbit/s via multiple channel aggregation[1]. MIMO and Adaptive Antenna Steering (AAS) can be used to enhance WiMAX throughput. In addition, WiMAX supports bandwidth management via centralized bandwidth scheduling in both uplink and downlink directions. This allows efficient resource allocation and hence higher achieved capacities. Newer WiMAX backhaul products can be deployed as point-to-multipoint base stations with 6 sectors with each sector supporting a throughput of 6 E1 links. Higher packing efficiency is indeed desirable for backhaul networks as it allows supporting more E1 connections per WiMAX link.

Timing and synchronisation in packet networks

By moving wireless traffic onto Ethernet, carriers can maximise the efficiency of their backhaul networks. But, unlike TDM, Ethernet does not inherently support network synchronisation. This capability is particularly critical in cellular networks as voice and video traffic must be delivered in real time. To support this requirement synchronisation must be maintained from one cellsite to the next to support seamless handoffs. The two methods receiving the most serious consideration are the IEEE standard 1588 v2 and the ITU *Synchronous Ethernet (Sync-E) standard*[2]. Sync-E operates at Layer 1 of the communication stack and distributes timing signal in a fashion similar to TDM networks. In Sync-E, each node recovers the clock information from the upstream node, filters jitter and wander via DPLL and then distributes to downstream nodes via physical layer regardless of the higher layer transmission protocols. Synchronous Ethernet can satisfy the requirements of cellular networks timing accuracy as it was shown to achieve < 2 ppb Accuracy[1]. Sync-E requires hardware support in all devices in the network from Central Office to Base Station. The other method, IEEE 1588 v2 is a protocol that runs in parallel with data traffic. It is also known as IEEE 1588 PTP(Precision Timing Protocol). An IEEE1588v2 protocol implementation can supply FDD and TDD radio systems and CES-based (circuit emulation services) transport systems with the synchronization signals they require. To implement it, the service providers must install a device know as a grand master clock in the central office. PTP was shown to achieve frequency accuracy below the required 50 ppb as discussed[1]. Unlike 1588 v2, Sync-E is not affected by traffic delays or other network changes. Sync-E is likely to be implemented in other industries like transportation and utilities and as a result may give benefits of significant economies of scale. Also because it is not sensitive to network congestion, jitter and delay, Sync-E does not complicate traffic engineering and planning. Packet based methods, such as IEEE 1588 can be combined with Synchronous Ethernet to circumvent its end-to-end connectivity requirement and allow traversing multiple domains.

There has been a recent effort in the IETF under the Timing over IP Connections and Transmission of Clock (TICTOC) working group to propose a unified framework for frequency and timing distribution over packet switched networks. The TICTOC architecture is based on frequency distribution and time distribution layers carried over the network by the timing protocol, e.g., NTP, IEEE 1588 PTP.

4G and phase synchronization[2]

As network operators plan to roll out 4G wireless networks, they must consider upgrading their networks to support synchronization. A critical element of 4G wireless standards, such as LTE and WiMax, is the ability to re-use the same wireless frequency in different phases—a capability that enables 4G networks to serve more customers on the same frequency range, thereby enabling the network to operate more economically. To support this capability, network operators will need a synchronization method that supports phase synchronization. Currently 1588 v2 supports phase synchronization but Sync-E does not. 4G network operators planning to deploy Sync-E may also need to support 1588 v2 in order to obtain phase synchronization capability. The requirement for phase synchronization also impacts the physical design of the carrier's transport equipment because separate output interfaces to the base station are required for phase and frequency synchronization.

References: There are many to be individually acknowledged, the primary ones are cited here:

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