Alcatel·Lucent

TECHNOLOGY WHITE PAPER

LIGHTRADIO Portfolio: White Paper 1

Technical overview

Wireless operators are facing exponential growth in adoption rates, as well as device capabilities. As this trend continues, existing networks and architectures will not be able to deliver the required performance — or maintain costs at an economically sustainable level. To address these challenges, lightRadio™ offers a new wireless networking paradigm, which can add sufficient capacity, in the right location, with the right technology, to optimize the end-user experience along with operator economics. This paper provides an overview of the lightRadio paradigm developed by Alcatel-Lucent and Bells Labs, including technology components, transport options — and the total cost of ownership savings that can be realized.

This paper is one in a series authored by Alcatel-Lucent that discuss the current state of wireless networks and the benefits of transitioning to a lightRadio architecture that supports data and video traffic, now and well into the future.

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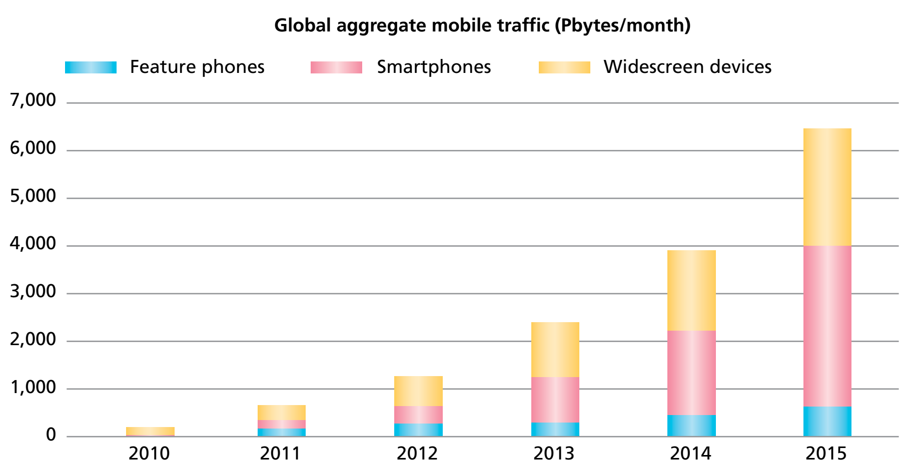
1. Introduction

The wireless industry is at a turning point. The confluence of end-user demand and proliferation of devices with advanced media capabilities is manifestly at odds with the cost and performance of *existing* wireless networks and architectures. Recognizing this dichotomy, along with emerging trends in key underlying technologies, Alcatel-Lucent and Bell Labs are creating a new wireless networking paradigm: lightRadio. This paper outlines the essential elements of a lightRadio network and the dramatic impact they can have on network economics and end-user experience.

2. The consequences of accelerating wireless demand

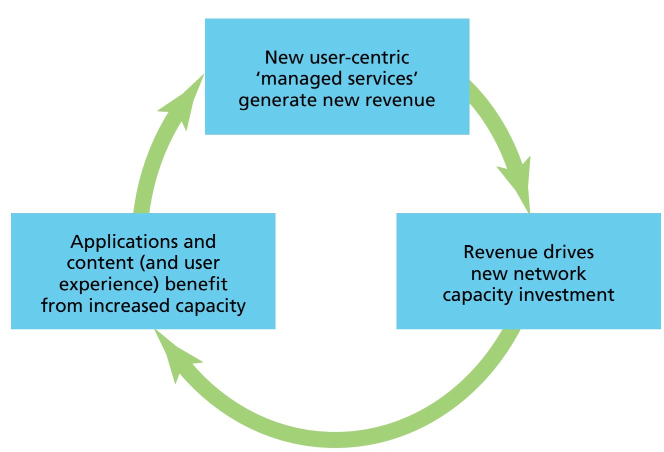
Growth in wireless devices is widely recognized to be exponential, in terms of both adoption rates and device capabilities. But the recent emergence of widescreen devices, such as tablet computers and advanced multimedia smartphones, has brought another dimension to traffic growth forecasts for the coming years. Figure 1 shows a view of how such devices will drive bandwidth demand.

Figure 1. Traffic growth projection for wireless networks



As devices such as these become widely available, developers will increasingly focus on producing new applications that showcase device capabilities. These applications, in turn, enhance the end-user experience and drive new levels and patterns of usage; for example, increased streaming of entertainment-quality video in high-definition. This trend increases the value of the wireless network infrastructure, which in turn reinforces the demand cycle.

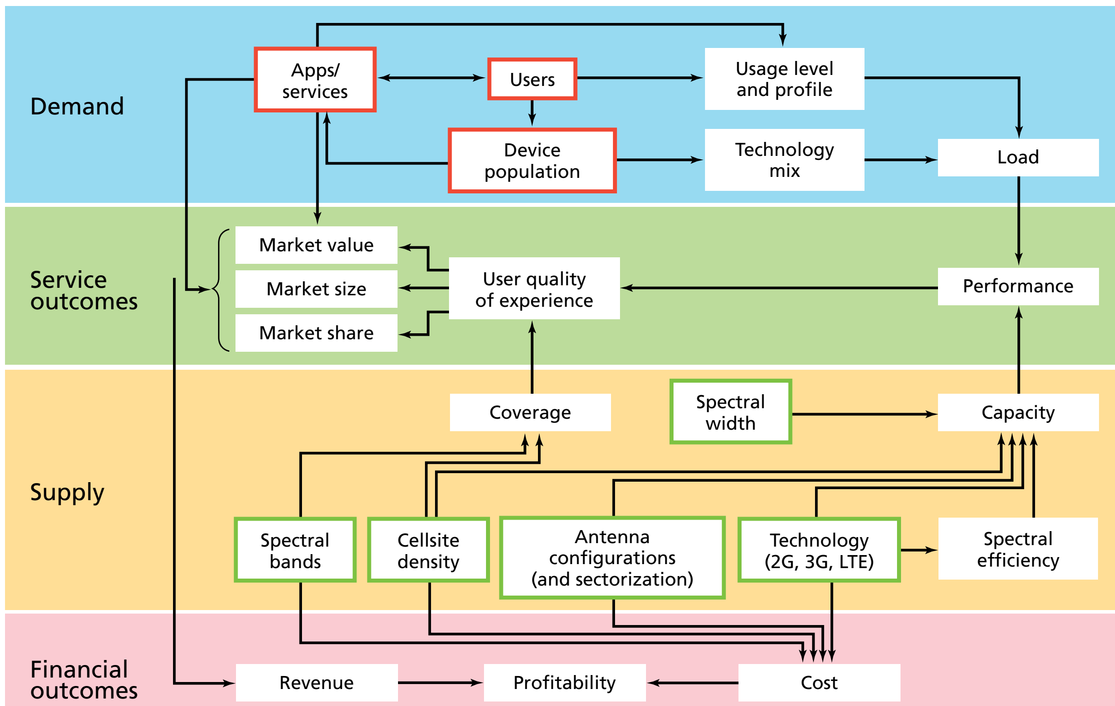
Figure 2. The virtuous — or vicious — cycle of demand



This can be a desirable or "virtuous" cycle when the cost of network expansion is offset by concomitant revenue growth. However, with current network architectures and deployments, this is no longer the case. The cost of acquiring new spectrum, deploying new wireless carriers and evolving network technologies (for example from GSM to W-CDMA to LTE), while adding more processing capacity, new radios and antennas — and managing the resulting heterogeneous network — is becoming economically unsustainable and leading to a "vicious" cycle of demand.

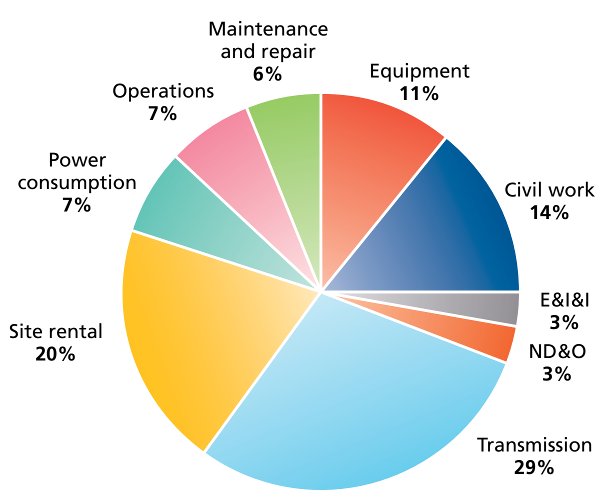
Figure 3 shows the complex interplay of factors in more detail. On the supply side of the problem, two factors affect service outcomes: coverage and capacity. Coverage is driven primarily by cell site density and the transmission frequency band, while antenna configurations and wireless technology also play an important role. Capacity is determined by the same factors, as well as spectral efficiency, which is affected by the type of wireless technology. Higher spectral efficiency is achievable, for example, with LTE.

Figure 3. Complex interplay of demand and supply, with service and financial consequences



Five key supply factors optimized by the lightRadio paradigm are highlighted in Figure 3. These five factors directly impact network costs, so any architectural shift must seek to minimize costs, especially in key categories such as transmission, site rental, civil works, equipment, power, maintenance, repair and operations, which are shown in Figure 4.

Figure 4. Breakdown of network costs

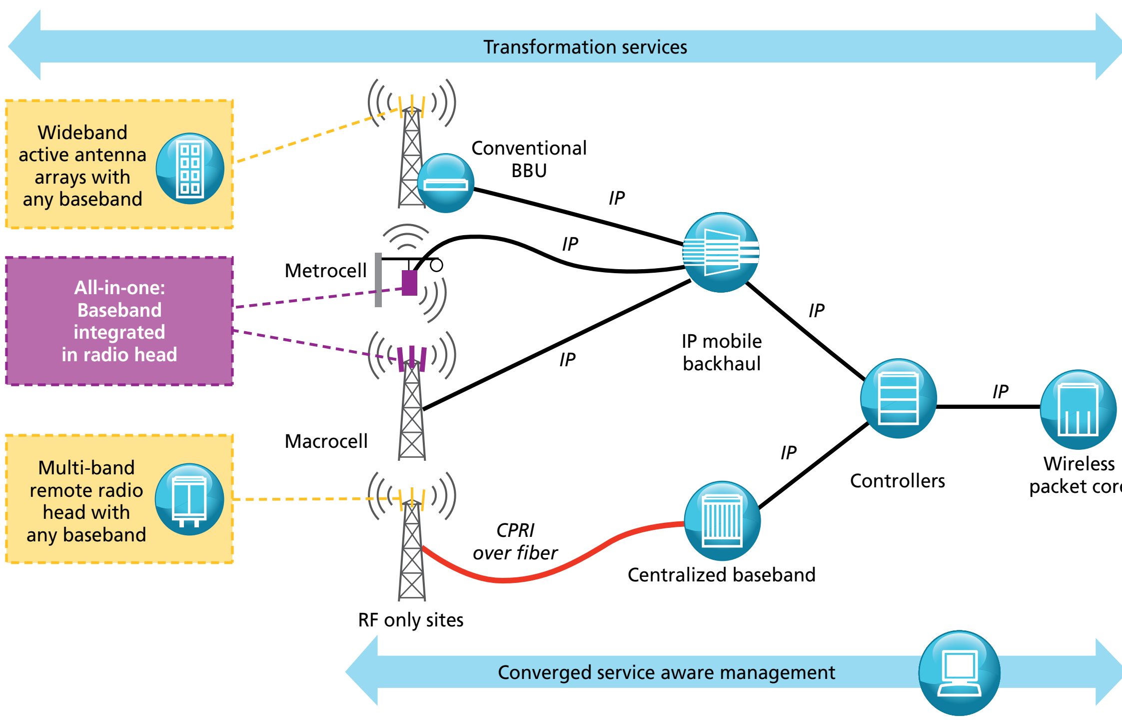


Design of the lightRadio product family focused on the entirety of network costs over time, including the long-term total cost of ownership. Consequently, the lightRadio solution architecture is economically attractive — and can leverage each operator's unique existing assets and capabilities. This paper will quantify the total cost of ownership savings associated with the lightRadio networking paradigm.

3. The lightRadio paradigm

Five key business enablers of the lightRadio paradigm are all aimed at adding sufficient capacity, in the right place, with the right technology, to simultaneously and continuously optimize end-user experience and operator economics. Figure 5 shows the essential lightRadio architecture, highlighting two different wireless scale points — conventional macro cells and smaller "metro cells" — as well as three different baseband processing configurations: baseband processing in the radio head (all-in-one), processing at the base of the tower (conventional baseband units) and centralized, pooled baseband processing ("in the cloud").

Figure 5. lightRadio architecture overview, with antennas, radios, baseband, controllers and management



The five technology components of the lightRadio product family are also identified. They include antennas, radios, baseband, controllers and management. These elements collectively create the following five business enablers, which optimize capacity, coverage and performance:

1. Seamless increase in spectral bandwidth
2. Optimization of cell site capacity
3. Optimization of technology evolution
4. Maximum utilization of new spectral bands
5. Optimization of antenna configuration

3.1 Business enabler 1: Seamless increase in spectral bandwidth

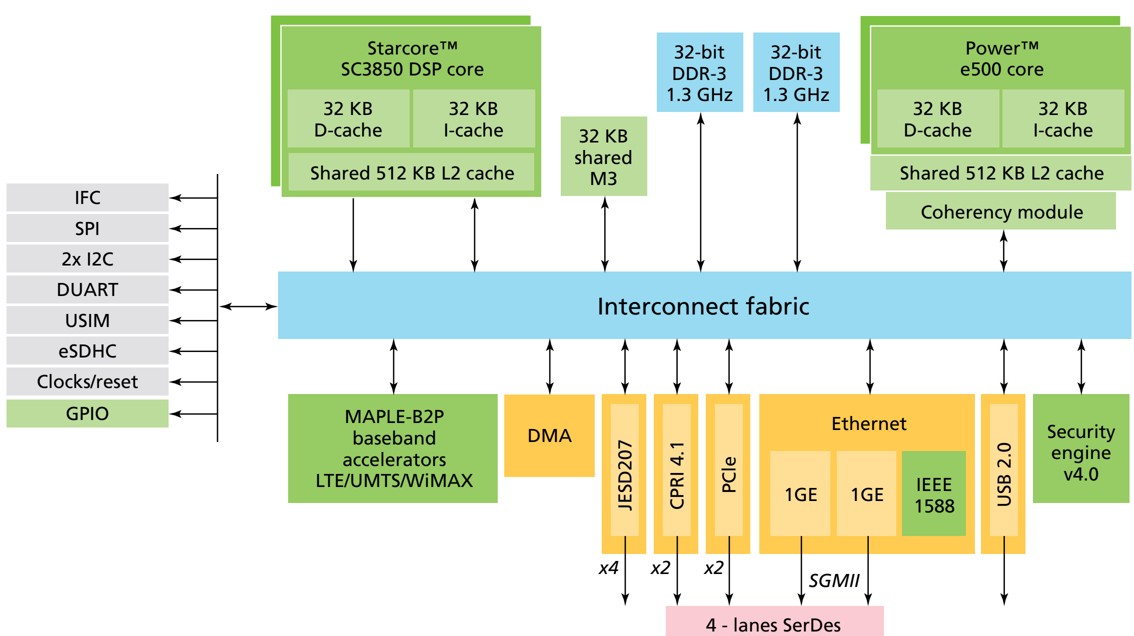
The first choice for augmenting capacity is to increase the number of carriers (the method used by W-CDMA) or improve the spectral bandwidth of each carrier (LTE's method), preferably in the same band as existing deployed radio carriers. This approach usually provides the least-expensive solution, since the same equipment practice and radio technology can often be re-used, though with expanded capacity. If spectral bandwidth increases are in a new frequency band, there is no clear advantage to using the same generation of wireless technology, since new antennas, radios and baseband equipment will be required. However, capacity needs to be matched not only to the demand in specific locations but also to the device population and related usage intensity. Therefore, a combination of existing and emerging technologies is required. lightRadio makes this possible with optimal economics.

lightRadio enables operators to "get it right" when deploying a solution to match user demand or expectations, while continuously optimizing the overall solution — all the way from the antenna to baseband processing and controller elements.

Baseband digital processing modules are built on a new System on a Chip (SoC) technology that incorporates a number of previously discrete, technology-specific components into a single, low-cost, high-performance device that is technology agnostic. In addition, it is remotely programmable to accommodate changing features and even changing radio technologies. Therefore, when W-CDMA customers shift to new LTE-based devices, the baseband module that has been serving them can be remotely reprogrammed as an LTE baseband module.

In addition, increases in spectral bandwidth can be seamlessly accommodated, when combined with advanced load-balancing and modem-pooling functions, as described later in this paper. Finally, wideband radios and adaptive antennas enable broadening of an existing spectral band — or extension to a new band — without adding an entirely new radio and antenna to the cell tower.

Figure 6. PSC9132 Metro SoC



3.2 Business enabler 2: Optimization of cell site capacity

Deploying additional carriers and spectral bandwidth increases available capacity. But if expansions are in new spectral bands, they may require expensive spectrum acquisition with a much broader geography than the locations where demand has peaked. For example, a dense urban site might need four carriers or more of W-CDMA for capacity reasons, but this is probably much more than a rural location needs. In contrast, increasing a cell site's density increases the effective serving capacity using existing spectrum assets. This is the key reason for deploying smaller macro cells and metro cells, sometimes called "pico cells."

Deployment of smaller macro cells offers sectorized, consistent performance throughout the cell, in all directions. However, finding new sites in dense urban areas can be difficult. Increasingly, the location of the radio and antenna provides no space for a conventional rack-mounted baseband unit in a temperature-controlled enclosure at the base of the tower. Thus, one of two approaches can be taken for macro cells:

- Put all baseband processing into a single unified multi-technology base station
- Transport baseband radio signals to a centralized location where the baseband processing equipment can be located.

These approaches are complementary. The choice depends on the availability of necessary backhaul bandwidth, the dynamism or elasticity of demand patterns and the operational costs. Therefore, both approaches are supported by the lightRadio paradigm.

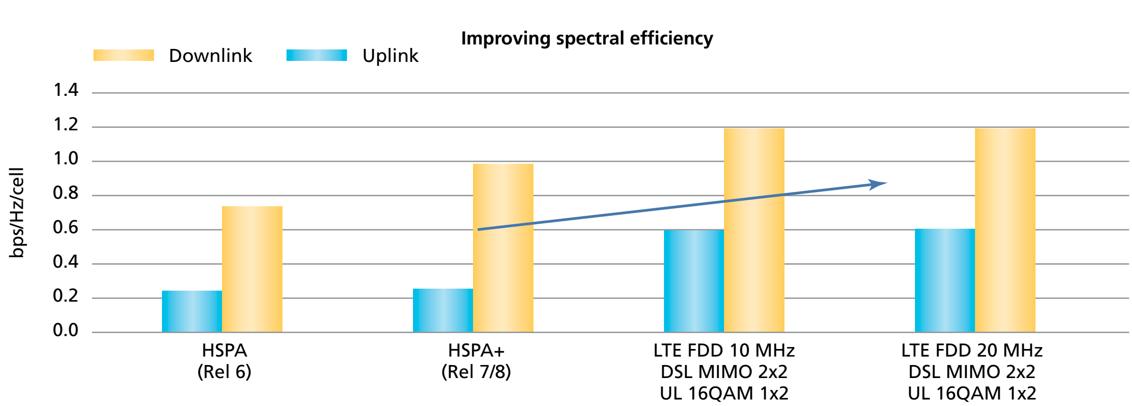
Outside of urban areas, sites are often served by microwave, when backhauling of Common Public Radio Interface (CPRI) signals to a central location is not cost effective and a more traditional baseband unit (BBU) provides the best fit. Considering an operator's entire network footprint — and the many infrastructure configurations comprising the network — it is clearly undesirable to change the available features when a user moves between cells or locations or, equally, to invest in network assets that will have a limited effective lifetime. Consequently, consistent functionality and re-usable common hardware and software components are a primary part of the lightRadio product family. These advantages are provided by common digital baseband components across different products and radio technologies.

Another way to increase cell site density is to introduce smaller cells, or "metro cells," at cost-effective site locations with the requisite backhaul and power sources. Metro cells do not typically provide contiguous coverage, but they augment a macro network in "hot spots" that have high traffic density. In the lightRadio paradigm, metro cells are built on the same SoC technology as the macro cells discussed earlier, and they leverage the same backhaul resources.

3.3 Business enabler 3: Optimization of technology evolution

Deployment of new wireless technology, often in new frequency bands, provides another means for increasing capacity and optimizing network economics. For example, an operator may deploy LTE in a new frequency band, such as 700 MHz or 2.6 GHz, in a new antenna configuration such as a 4 x 4 multiple-input multiple-output antenna system (MIMO). This deployment anticipates, and may even fuel, the user-device population's shift from 3G to LTE, while it diverts traffic from overloaded 3G carriers. With the higher spectral efficiency of LTE, the operator will have more effective capacity and performance in the new frequency band than with 3G or 2G, as shown in Figure 7.

Figure 7. Peak throughput and latency of primary radio access technologies (Source: Bell Labs modeling)



This progression will continue with LTE-Advanced, which provides carrier aggregation ("bonding" together separate frequency bands) and advanced methods for coordinating multiple base stations, such as coordinated multipoint transmission and reception (CoMP) and dynamic inter-cell interference coordination (ICIC). CoMP will increase the effective spectral efficiency and positively affect end-user performance.

This technology evolution is not unique to the lightRadio concept. But lightRadio supports both current and anticipated wireless technologies in the following unique way: The baseband module (whether in the centralized or remote architecture) is dynamically reprogrammable to support multiple combinations of W-CDMA and LTE technologies and their evolution. Thus, an operator could start with a baseband that is 100 percent W-CDMA and evolve over time by simple remote software reconfiguration until, at some stage, the same hardware is used 100 percent for LTE.

lightRadio also optimally supports the developments anticipated in LTE-Advanced and 3G by allowing seamless migration of baseband processing from the remote site to a centralized baseband processing pool.

In addition, Alcatel-Lucent innovations extend the concept of self-optimizing networks (SON). They apply a new layer of understanding, called "wireless IP intelligence," to optimization across the entire network, including the RAN, packet core and both licensed and unlicensed spectrum assets, such as WiFi access points. This end-to-end optimization is critical for responding to rapidly changing demand patterns — and helps anticipate the need for coherent metro cell and macro cell optimization, as metro cells are installed opportunistically in demand "hot-spots."

3.4 Business enabler 4: Maximal utilization of new spectral bands

Deployment of capacity in new spectral bands usually carries significant costs for spectrum acquisition and new equipment. If the new band is lower in frequency than existing bands, such as 700 MHz, coverage will improve, because lower frequency bands exhibit superior propagation characteristics and cell reach. Deployments in higher frequency bands, such as 2.6 GHz, will have more limited reach, which can result in coverage holes between base stations, particularly when sites were chosen based on a lower-frequency spectral band. For example, at 2600 MHz, LTE has one-third the cell radius of W-CDMA at 900 MHz.[1] Thus, deployment in higher bands may create "patchy" services where there are frequent fallbacks from LTE to 3G, or even 2G; or, significant additional expense may be incurred to fill in these coverage holes. Operators are moving to four- and even eight-branch receive diversity[2] to help cover the link budget gap.

Again, lightRadio has a unique advantage, because it allows the capital expenditure associated with multi-band deployment to be dramatically reduced through use of radios that can operate across multiple spectral bands. Further, new radios can assist with some additional mechanical tower loading issues, in particular for new sites.

1 WCDMA at 900 MHz, 40W MC-RRH, xCEM, UL cell edge target rate PS64 HSUPA, Cat 3 HSUPA UE. LTE at 2600 MHz, 10 MHz BW, UL cell edge target rate PS128, average across all morphologies.

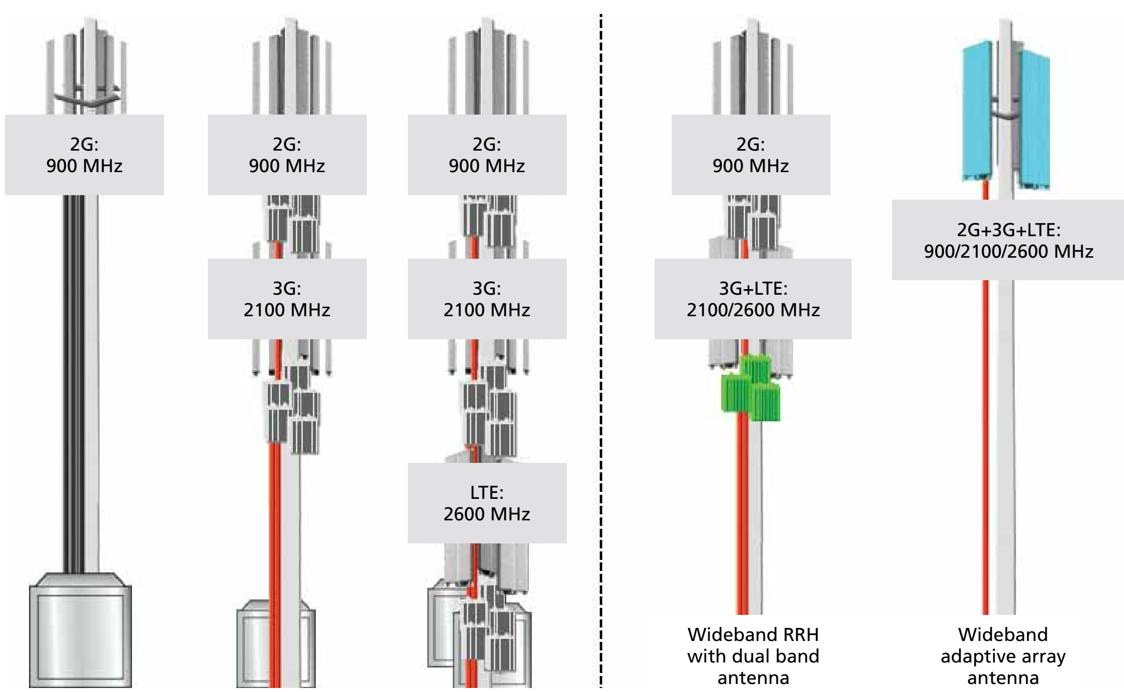
2 Receive diversity provides protection against fading by using another copy of the signal from the user on an additional antenna (a different "branch") because the fading and noise are uncorrelated between the different antennas. This also allows the user to transmit at lower power, which decreases interference. However receive diversity requires additional receiver chains in both the RF and baseband components, and improvements tail off rapidly with increased branches, since the improvements are less than linear. Improvements from averaging out the RF noise however (introduced by the RF chain in a receiver) do increase linearly.

To understand tower loading issues, consider that, to achieve the required power and efficiency, most cell site builds currently put the radio on the tower in a remote radio head (RRH) configuration, rather than at the bottom of the tower — driving an antenna up on the tower. Macro cell sites are typically divided into three sectors, and today a separate RRH is required for each frequency band, even though the RRH is generally radio technology agnostic. Some carriers have sites with five different frequency bands in three sectors, leading to 15 remote radio heads on a cell tower. This type of arrangement is shown in the left panel of Figure 8. Compounding this issue, multiple operators frequently share each tower, with the tower leased from a third-party provider. Now the situation is only getting worse, as new antenna configurations, such as MIMO with four transmit and four receive antennas, increase complexity even further. As a result, the size, weight, wind loading, visual appearance and leasing costs of the tower have become blocking issues for the evolution of radio networks.

Although a tower is illustrated here, these problems are most acute for dense urban areas where the RF equipment is more typically mounted on the top or side of a high-rise building or on a mast.

As depicted in the right panel of Figure 8, lightRadio significantly reduces this problem. It also allows continued evolution in radio capacity, well into the future, by utilizing wider frequency band radios which can be incorporated into a smaller number of lightRadio RRHs.

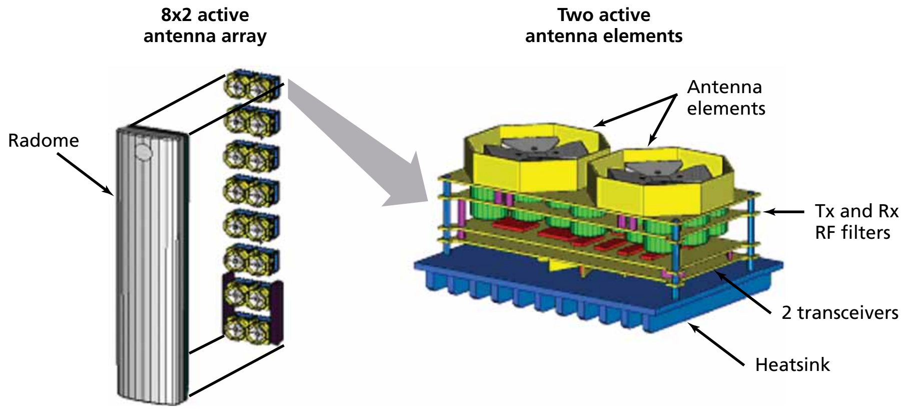
Figure 8. Current and future radio heads on cell towers - with lightRadio paradigm



3.5 Business enabler 5: Optimization of antenna configuration

Improved antenna configurations are designed to enhance the user experience by optimizing the consistency of capacity and coverage. Historically, such improvements have been made by establishing multiple passive transmit and receive antennas for a particular radio and technology; for example, using MIMO.

Figure 9. Innovative active antenna array in lightRadio architecture



The lightRadio family significantly extends antenna technology using smart active antenna arrays (AAAs). This advance can obtain MIMO gains and allow sophisticated beamforming, so the RF energy can be dynamically directed exactly where needed, based on dynamic changes in cell loading and traffic density. Figure 9 illustrates one novel AAA design that is part of the lightRadio product family.

The AAA design offers a range of benefits. It can provide significant improvements in capacity through vertical beamforming. It lowers power consumption by improving coverage, and it also improves antenna robustness because the array can be reconfigured to mitigate the impact of individual element failures. The lightRadio family includes active antenna arrays in addition to, and in combination with, conventional passive antennas. In combination with centralized baseband processing, these antenna solutions allow advanced ICIC schemes to be supported between neighboring cells, enabling significantly improved signal-to-noise ratios.

In summary, lightRadio combines adaptive, multi-band and multi-technology elements, in the antenna, radio and baseband processing, along with virtualization, cloud principles and architectural flexibility. This combination can achieve radical reductions in operators' total cost of ownership, helping to grow their networks to meet coming demands.

Next, this paper examines the subject of cloud-based baseband pooling, compared with local (remote) baseband processing, including their ability to support each configuration over different backhaul infrastructures, namely copper, fiber and microwave.

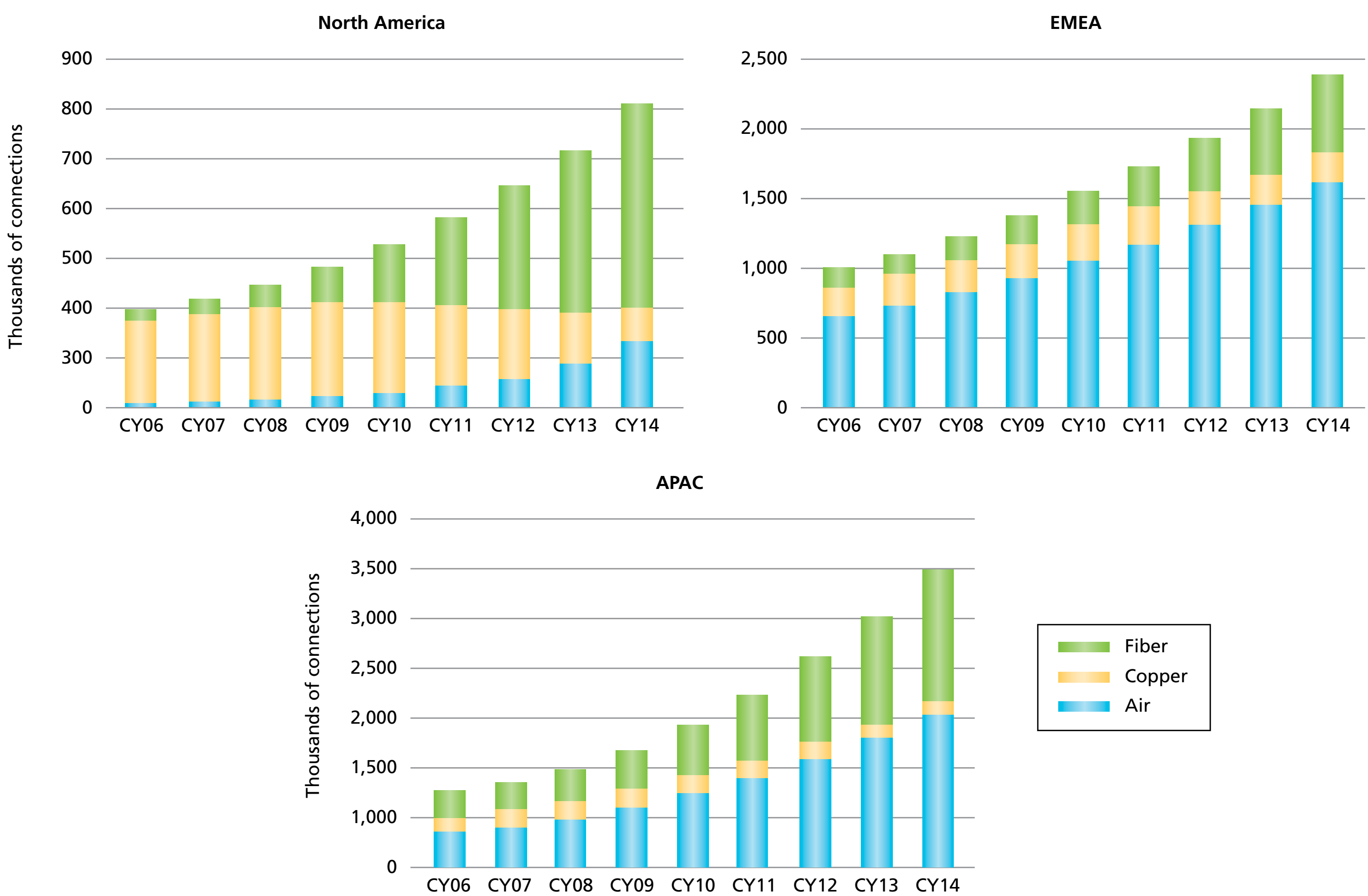
4. Transport options for lightRadio

lightRadio can be considered to have two "canonical" baseband processing options, as shown in Figure 5, with distinct backhaul requirements:

- Process baseband signals on the remote cell site in a baseband unit (BBU) at the base of the cell tower — or integrated with the radio head (all-in-one BTS). This option requires backhaul of asymmetric, latency-insensitive, relatively low-bit-rate streams of native IP traffic, which this paper calls "IP backhaul."
- Process baseband signals in a central location as part of a pool of resources "in the cloud." This approach requires backhaul of quadrature amplitude modulation (QAM) sampled antenna waveforms which are symmetric, latency sensitive and typically high bit rate. This method will be called "IQ sample stream transport," or just CPRI transport, referring to the Common Public Radio Interface (CPRI) specification typically used to transport these signals. The following analysis will also consider novel, more highly compressed forms of CPRI.

To minimize capital expenditures, operators need to reuse their existing infrastructure assets (which may be leased from another provider). Copper pairs are still used quite extensively in North America, typically configured as T1 lines or bonded SHDSL. Figure 10 shows the relative proportion of copper, fiber and air (microwave) backhaul infrastructure deployed today, and predicted for the future, for three different regions. Fiber and air interfaces are clearly beginning to dominate, although a non-negligible amount of copper backhaul will continue to exist, particularly as fiber-to-the-node architectures become increasingly prevalent, and as vectoring (crosstalk cancellation) and phantom mode technologies are deployed. Microwave connectivity tends to be used for long distances or over terrain where laying fiber is prohibitively expensive. Fiber is used where trenching is relatively inexpensive, or where very high bandwidth is required.

Figure 10. Backhaul technologies used in three regions (Source: Infonetics, September 2010)



Each backhaul technology has different bandwidth and latency metrics. Table 1 provides a summary of the capabilities — and different infrastructure configurations — that will be considered in the following analysis.

Table 1. IP backhaul/IQ sample stream transport infrastructure options and performance metrics

OPTION	CONFIGURATION		INFRASTRUCTURE AND TECHNOLOGY CAPABILITY	
			BANDWIDTH (MB/S)	LATENCY (MS)
1	Copper	2 pair bonding with vectoring and phantom mode 1500 m	100 down 20 up	3
2		4 pair bonding with vectoring and phantom mode 1500 m	230 down 40 up	3
3		8 pair bonding with vectoring and phantom mode 1500 m	750 down, 150 up	3
4	Microwave	11-23GHz (Up to 16 km at 11 GHz) 254 bits per frame	305 down, 306 up per radio	~0.15 per hop
5		80 GHz (up to 1.5km)	1000	~0.15 per hop
6	Fiber	10 Gb/s point to point fibre	10,000	0.1 + 0.005/km
7		CWDM	8 x 10,000 per fiber pair	0.005/km

4.1 IP backhaul options

First, the analysis will consider the IP backhaul options (baseband processing at the cell site) for different cell site radio configurations. Figure 11 shows the bandwidth required to serve up to 4 x 5 MHz carriers of W-CDMA, together with 0 MHz to 30 MHz of LTE spectrum with a 4 x 2 MIMO antenna configuration, all with three sectors. It also summarizes the ability of copper, microwave and fiber infrastructures to support this bandwidth.

As Figure 11 indicates, IP backhaul transport can be supported over:

- *Copper:* An FTTN configuration with eight bonded pairs of VDSL with vectoring and phantom mode VDSL is capable of supporting even the largest base station configuration considered.
- *Microwave:* An air interface in the 6 GHz to 23 GHz spectral range is also valid for these cell site configurations, with only the largest configurations needing a second microwave radio.
- *Fiber:* Point-to-point or WDM PON fiber architectures are clearly capable of providing backhaul for any of these cell site configurations, given the 10-Gb/s capacity per link or wavelength. For TDM PON, commonly deployed in the access layer, a single 10-G PON could also support backhaul of multiple cell sites with any of the configurations considered.

Figure 11. Effectiveness of varied infrastructures for IP backhaul of cell site traffic, with different combinations of W-CDMA and LTE carriers

5 MHz WCDMA carriers	LTE spectral bandwidth (MHz)			
	0	10	20	30
0	0	60	120	180
1	26	86	146	206
2	52	112	172	258
3	78	138	198	336
4	104	164	224	440

a) Copper: Color denotes 2, 4 or 8 pairs as per Table 1

5 MHz WCDMA carriers	LTE spectral bandwidth (MHz)			
	0	10	20	30
0	0	60	120	180
1	26	86	146	206
2	52	112	172	258
3	78	138	198	336
4	104	164	224	440

b) Microwave: Color denotes 1 or 2 carriers in the 6-23 GHz range as per Table 1

5 MHz WCDMA carriers	LTE spectral bandwidth (MHz)			
	0	10	20	30
0		166	83	55
1	384	116	68	48
2	192	89	58	38
3	128	72	50	29
4	96	60	44	22

c) Fiber: Numbers indicate number of cell sites (base stations) that can be served by a single 10G PON

4.2 IQ sample stream transport options

Next, this section will consider the bandwidth required for IQ sample stream transport to a centralized baseband processing unit or pool. The left panel of Figure 12 shows the raw CPRI rates required for each cell site configuration. The right panel shows the bandwidth required when using new compression algorithms from Bell Labs, which achieve a factor of three reduction with negligible signal degradation.

Figure 12. Bandwidth (in Mb/s) required for IQ sample stream transport to a centralized baseband processing function

Uncompressed IQ sample streams

5 MHz WCDMA carriers	LTE spectral bandwidth (MHz)			
	0	10	20	30
0	0	5530	11059	16589
1	462	5992	11521	17051
2	924	6454	11983	17513
3	1386	6916	12445	17975
4	1848	7378	12907	18437

Compressed IQ sample streams

5 MHz WCDMA carriers	LTE spectral bandwidth (MHz)			
	0	10	20	30
0	0	1842	3683	5525
1	462	2304	4145	5987
2	924	2766	4607	6449
3	1386	3228	5069	6911
4	1848	3690	5531	7373

Bandwidth in Mb/s for IQ sample streams between a remote site and a centralized baseband site. Downlink traffic only.
WDMA 2 transmit antennas, LTE 4 transmit antenna. Calculation is for 3 sectors. Rates exclude CPRI framing and control overheads.

By comparing Figure 12 with the capacity of different infrastructure options summarized in Table 1, it becomes clear that any of these configurations require fiber backhaul to support IQ sample stream transport. Key findings regarding IQ sample stream transport over copper, microwave and fiber include:

- *Copper:* Even the most advanced DSL configuration (eight bonded pairs with vectoring and phantom mode) does not have sufficient capacity for IQ sample stream transport. Moreover, DSL adds an additional 3 ms of delay to the propagation and sampling/processing delay, which does not compare favorably to the 2 ms to 3 ms maximum delay required on downlink (with channel state updates, 2 GHz carrier and pedestrian mobility speeds).
- *Microwave:* There is insufficient bandwidth to support IQ sample stream transport mode. 80 GHz (millimeter band) microwave could support 1 x 5 MHz W CDMA carrier (only), but this is not an economically viable option.
- *Fiber:* TDM PON is also unattractive for IQ sample stream transport, because of the latency introduced. Even if this could be overcome, the bandwidth required for a *single* base station supporting three carriers of W-CDMA plus 20 MHz LTE will use advanced compression, and nearly fill more than half the capacity of an entire 10-G PON. Thus, only point-to-point fiber links — or WDM with multiple wavelengths over a shared fiber — represent viable options for Macro-cell IQ sample stream transport.

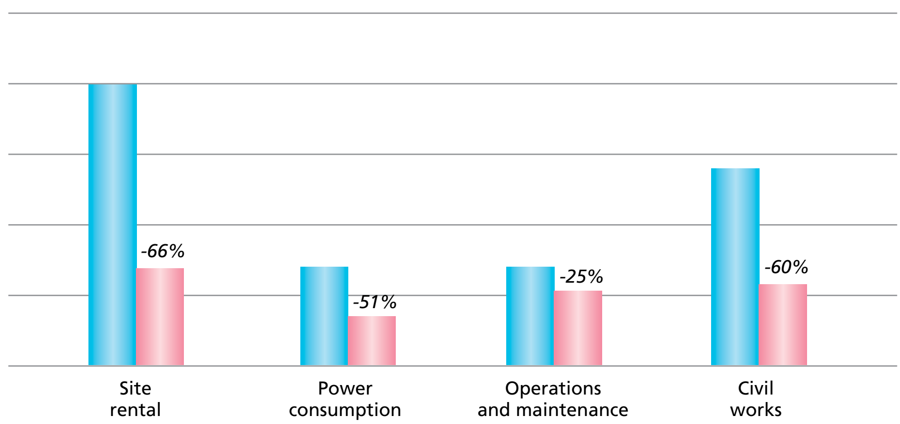
These findings confirm the value of supporting both local baseband processing at the cell site, as well as a centralized baseband processing option. This architectural flexibility allows the widest deployment with reuse of existing infrastructure, using a combination of IP backhaul and IQ sample stream transport. This flexibility also allows optimization of the total cost of ownership, as well as the time to deployment. Further details of this subject can be found in *lightRadio White Paper 3: Customer solutions.*

5. Total cost of ownership savings

Savings in TCO that can be realized with the lightRadio paradigm have been quantified, and the results are summarized in Figure 13. Depending on geography and other customer-specific conditions, lightRadio can reduce TCO by at least 20 percent over five years for an existing high-capacity site in an urban area — and by at least 28 percent for new sites. These savings come primarily from the following elements:

- For dense urban areas where new sites must be established but the logistics of locating temperature controlled enclosures are difficult, the baseband can be centralized or combined with the radio head to leave no "footprint." This not only eliminates civil works and site rental costs, but also reduces power consumption since heating and cooling cost of the enclosure are eliminated. It is even possible in some cases to use assured AC power to eliminate on-site battery backup.
- On-site work to provision, commission, install, repair, augment and upgrade a cell site are all decreased by use of wideband antennas/radios (due to reduced installs, civil works and devices to manage) — and centralized or remotely programmable baseband hardware.

Figure 13. lightRadio TCO benefits – a breakdown



Further details of this subject can be found in *lightRadio White Paper 2: Benefits and Economic Proof Points*.

6. Conclusion

The new lightRadio paradigm addresses all the key business needs of wireless operators, by optimizing the future wireless network in five key dimensions. To achieve these enhancements, it uses a flexible array of core technology innovations in antennas, radios and baseband processing, which are all deployed in a flexible architecture. Moreover, easy reconfiguration and software reprogramming of network elements allows the operator's TCO to be continuously optimized over time, as demand increases — and as the network evolves to smaller cells, with loads that vary dynamically as a function of time of day and ever-changing services needs. In these crucial ways, lightRadio truly represents a wireless network revolution for operators and end users alike.

7. Acronyms

AAA	Active Antenna Array
BBU	Baseband (Digital processing) unit
BTS	Base station (Antenna + Radio + Baseband)
CDMA	Code Division Multiple Access
CO	Central Office
CoMP	Coordinated Multipoint Transmission and Reception
CPRI	Common Public Radio Interface
CWDM	Coarse Wave Division Multiplexing
DSL	Digital Subscriber Line
DWDM	Dense Wave Division Multiplexing
E1	European Multiplexed Carrier 2 Mb/s over copper pair
FTTN	Fibre to the Node
G.Vector	ITU-T standard G.993.5 DSL crosstalk reduction method
GGSN	Gateway GPRS Support Node (for W-CDMA)
GigE	Gigabit Ethernet
GSM	Global Standard for Mobile communication
LTE	Long Term Evolution
LTE-A	Long Term Evolution –Advanced
MIMO	Multiple Input Multiple Output antenna system
MME	Mobility Management Entity (for LTE)
PGW	Packet Gateway (for LTE)
PON	Passive Optical Network
RAN	Radio Access Network
RNC	Radio Network Controller (W-CDMA)
RRH	Remote Radio Head
SGSN	Serving GPRS Support Node (for W-CDMA)
SGW	Serving Gateway (LTE)
SOC	System On a Chip
T1	North American Multiplexed Carrier, 1.54 Mb/s on copper
VDSL	Very high bit rate Digital Subscriber Line
VPLS	Virtual Private LAN Service
W-CDMA	Wideband Code Division Multiple Access
WDM	Wave Division Multiplexing

8. References

lightRadio White Paper 2: Benefits and Economic Proof Points
lightRadio White Paper 3: Customer solutions

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