Remote RF is Becoming a Mainstream Solution

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Abstract

This paper examines the technologies and applications associated with the extension of the connection between a wireless radio base station and its antennas. The extension of this connection allows wireless operators to provide wireless service to new and remote areas, using radio equipment from an existing location. Optical Wireless Technology is proposed as a viable and cost effective technology for this application in urban environments. The cost benefits of using today's technologies to extend the link between radio base stations and their antennas is also examined.

Executive Summary

The wireless telecommunications industry has experienced enormous growth over the last few years, driven primarily by wireless subscriber growth and most recently the promise of wireless data services. The demand for wireless services continues to grow throughout the world. At this point, global wireless telecommunications subscriber growth is about 20% annually. As the demand for wireless services has grown, wireless networks throughout the world have evolved to meet the demand, and provide improved subscriber services. This evolution has taken wireless networks from analog to digital, and through continuing changes in radio access technology to provide increased capacity and wireless data services.

Increasing wireless network capacity and evolving technology have presented numerous challenges to wireless service providers. First, it has become increasingly more difficult for wireless operators to find locations for wireless radio equipment. This is a problem in urban areas in particular. Urban areas present unique challenges, since they require higher capacity to accommodate a large number of subscribers, and it is often difficult to provide coverage inside buildings, indoor stadiums, tunnels and other structures. Rural areas present other challenges, with large coverage areas that must be served, trees and foliage, and low population densities. Above all, wireless service providers must cost effectively expand and improve their networks. In today's market place, there are a number of wireless service providers to choose from, and there is intense competition between operators for wireless subscribers. In order to survive in today's wireless marketplace, wireless service providers must be cost effective in operating and expanding their networks.

Over the last few years, wireless service providers have used various products to augment their existing radio equipment. These products provided access to the wireless network for subscribers that were in difficult places to reach, such as indoor shopping centers, offices, convention centers, and crowded urban areas. In most instances, these products provided remote radio equipment or remote access to radio frequencies by adding more compact radio equipment to the network, or providing remote access to existing equipment in the network. Remote access was typically provided by an additional radio frequency link (usually at a higher microwave frequency) from an existing radio equipment location to another location where coverage was needed, but it was not possible to install radio equipment in that area. This link extended the connection between the radio equipment and its antennas. Microwave radio links were usually bandwidth limited, which would limit the number of radio channels that could be transmitted to a remote location. Another method used to make the connection between existing radio equipment and antennas at a remote location is to transmit the radio signals over fiber optic cable. This solution provides a direct fiber optic cable connection between the existing radio equipment and the antennas at the remote location. The fiber connection provides much higher radio channel capacity and longer link distances. However, fiber can be much more difficult and expensive to install. Today, the connection between existing radio equipment and antennas at a remote location can also be made using an Optical Wireless link. This is essentially a light wave communication system, like fiber optic cable, that transmits a beam of light over the air. This technology provides the capacity advantages of fiber, and it easy to install. These systems require line of sight connections, and are subject to signal attenuations due to weather conditions, much like microwave radio systems. As a result, they may be best suited for dense urban environments, where the distance between the existing radio equipment and the remote antennas is relatively short.

Smaller, more compact radio base station equipment, such as the microcell, was also used to provide additional capacity to areas with high call traffic. Due to its compact size, this equipment was usually limited in terms of the number of radio channels it could support. Traditionally, wireless service providers have used these products in special circumstances.

This paper provides an overview of wireless remote radio products that are available to wireless service providers today, and also proposes a new method of wireless network deployment that makes use of remote radio products as the network is being expanded or deployed. The concept of using today's existing remote radio technology as a part of an overall network expansion or deployment strategy can provide significant cost savings for wireless service providers.
Using today's remote radio technology, operators can significantly reduce the installation time required for new wireless radio equipment, reduce their building

leasing costs, and reduce their overall operations and maintenance expenses. In addition, wireless service providers can achieve significant cost savings by aggregating the subscriber traffic from existing radio equipment locations and remote locations. The resulting consolidation of backhaul traffic provides a tremendous cost savings to wireless service providers and others who manage similar network facilities. Overall, the use of remote radio solutions can save wireless operators up to 40% on capital expenses, and as much as 60% on operating expenses.

By making use of today's advancements in remote radio technology as a part of an overall deployment strategy, wireless service providers can significantly decrease the time required for network deployment. They can accomplish this by avoiding costly and lengthy cell site construction processes. At the same time, they can achieve significant cost savings by utilizing the available remote radio technology and the wireless network design concepts that are presented. Using these concepts, wireless service providers can significantly reduce their capital and operating expenses. In addition, the cost savings increase as the design concepts and technology are implemented throughout the network.

Introduction

This paper will provide a brief overview of conventional wireless RF (radio frequency) network design concepts, and an examination of remote radio products. An update on current remote radio technology and possible applications will also be provided.

Distributed cell site architecture will be explored as a possible RF network design concept. The potential benefits of this concept will be described in detail.

Wireless Network Deployment

Traditionally, wireless service providers have installed and expanded their networks by deploying radio equipment in multiple locations throughout their service areas. In the early wireless network designs, these radio equipment installations were called "cells", hence the term "cellular". The locations themselves were often called "cell sites". Although wireless radio equipment technology has evolved, the process for deploying it has remained very much the same.

Obtaining a cell site location and deploying the equipment can be an expensive and time consuming process, especially in crowded urban areas. To begin this process, wireless service providers must select a cell site location. The desired location is determined based on factors such as coverage, capacity, network performance and site availability (given real estate zoning issues, etc.). The addition of a new cell can also make it possible for operators to reduce the signal levels of surrounding cells, thereby reducing interference and required signal levels for mobile telephones. Once a desired location has been determined, a real estate consultant (who may or may not work for the operator) is often used to find suitable properties for the site. Ultimately, each site must have the proper approvals from the local municipality, and the proper zoning classification before the operator can install the equipment. This alone can take a considerable amount of time, depending on the location of the site and local municipality.

Once the approvals have been obtained, the property must be equipped to store the radio equipment. This usually includes leasing of the appropriate amount of building space, leasing of exterior building space for antennas, installation of power, installation of air conditioning, installation of fire/security equipment and installation of backhaul facilities to transport call traffic between the mobile switching center and the cell site. The backhaul facilities are usually leased cable lines, microwave radio frequency links, or fiber optic cable. Additionally, ongoing maintenance is required for the radio equipment and the ancillary equipment at the cell site. Each site requires a significant capital expenditure and a significant operating expenditure for the wireless service provider. The following tables from Northstream, a European wireless technology consulting company, provide estimates for these expenses. These expenses are based on operator costs in Stockholm, Sweden, and are representative of an urban European market. The estimates will vary depending on the geographic region, and the individual market. BTS (Base Transceiver Station) equipment is assumed to be a new UMTS cell with one carrier.

Costs for a new cell site with leased line backhaul

All prices are in US$	Year 1	Year 2	Year 3	Year 4	Year 5
CAPEX					
NW planning	5,500				
Site Acquisition	5,000				
rooftop space	1,000				
indoor space	4,000				
Civil works	36,000				
CW for indoor (BS room, etc)	33,480				
CW for rooftop (antenna, etc)	2,520				
Leased line Connection	1,200				
Site Support	13,000				
Antenna poles	500				
Power	6,500				
Antenna line equipment	4,000				
Air-conditioning	1,500				
Fire/Security equipment	500				
BTS hardware and software	45,000				
Microwave link					
Total CAPEX	105,700				
OPEX					
Site Rent	4,500	4,500	4,500	4,500	4,500
rooftop space	2,250	2,250	2,250	2,250	2,250
indoor space	2,250	2,250	2,250	2,250	2,250
Leased Line (2Mbps) - 3% annual price erosion assumed	6,000	5,820	5,645	5,476	5,312
Electricity	1,600	1,600	1,600	1,600	1,600
Microwave license fee					
Operations and Maintenance	10,570	10,570	10,570	10,570	10,570
Municipal taxes	0	0	0	0	0
Total OPEX	22,670	22,490	22,315	22,146	21,982
Total	**128,370**	**22,490**	**22,315**	**22,146**	**21,982**

Data provided by Northstream

Table 1 – Itemized Capital and Operating Costs for a Leased Line Site

Costs for a new cell with microwave backhaul					
All prices are in US$	Year 1	Year 2	Year 3	Year 4	Year 5
CAPEX					
NW planning	5,500				
Site Acquisition	5,000				
rooftop space	1,000				
indoor space	4,000				
Civil works	36,000				
CW for indoor (BS room, etc)	33,480				
CW for rooftop (antenna, etc)	2,520				
Leased line Connection					
Site Support	13,000				
Antenna poles	500				
Power	6,500				
Antenna line equipment	4,000				
Air-conditioning	1,500				
Fire/Security equipment	500				
BTS hardware and software	45,000				
Microwave link	12,000				
Total CAPEX	116,500				
OPEX					
Site Rent	4,500	4,500	4,500	4,500	4,500
rooftop space	2,250	2,250	2,250	2,250	2,250
indoor space	2,250	2,250	2,250	2,250	2,250
Leased Line (2Mbps)					
Electricity	1,600	1,600	1,600	1,600	1,600
Microwave license fee	100	100	100	100	100
Operations and Maintenance	11,650	11,650	11,650	11,650	11,650
Municipal taxes	0	0	0	0	0
Total OPEX	17,850	17,850	17,850	17,850	17,850
Total	**134,350**	**17,850**	**17,850**	**17,850**	**17,850**

Data provided by Northstream

Table 2 – Itemized Capital and Operating Costs for a Microwave Backhaul Site

In addition to the expense involved, wireless service providers are also faced with a number of other challenges as they deploy new cells. As new cells are installed, the wireless network continues to grow and new subscribers are constantly being added. As a result, it is sometimes difficult for wireless service providers to keep pace with the growth of the network traffic. There are also situations when wireless service providers cannot obtain sites where they are needed, due to zoning issues or a failure to get the proper approvals from local municipalities. Some municipalities will not grant approvals in certain areas, and others will not grant approvals at all.

Although wireless service providers use an array of tools that measure and predict radio frequency propagation for all of the cells in the network, there are still locations within the network that lack the appropriate coverage or capacity. There are also areas where, despite the service provider's best efforts, it is extremely difficult to provide the coverage and capacity levels required. These include office buildings, convention centers, malls, campus environments, and sports arenas. There are also special events and changes in call traffic patterns that can make it very difficult for wireless service providers to put the coverage and capacity where it is needed.

Early Remote RF Solutions

Over the years, a number of products have been used by wireless service providers to combat coverage and capacity problems. These products were designed to provide remote coverage and capacity, and to fill in isolated high traffic areas and isolated areas of low coverage. These products included repeaters, microcells, and the COW (Cell on Wheels). Tower mounted amplifiers were also used to improve coverage. These amplifiers were mounted at the top of the antenna towers to increase the signal levels of the mobile telephones received at the base station, which are lower than the base station signals received by the mobile telephones. This improved coverage by balancing the transmit and receive signals between the mobile telephones and the base stations. While the tower mounted amplifiers could expand the coverage of an existing cell, repeaters provided coverage to a remote location.

Repeaters provide coverage to remote locations by using radio channel capacity from an existing cell. This "donor" cell provides existing capacity to a remote area. The repeater takes the radio signals from the donor cell and re-transmits them to a remote location via a high frequency microwave link, which includes transmit and receive frequencies. The signals are then converted back to mobile wireless frequencies and transmitted to mobile telephones in the remote area via standard radio frequency antennas. The repeater also re-transmits the mobile telephone signals back to the donor cell, using the same microwave radio link. Repeaters provide coverage. However, they do not provide additional capacity. Some repeaters amplify the signals from the donor cell to provide greater coverage in the remote area. Repeaters are effective when there is a lack of coverage in a given area, and there is a donor cell nearby with enough capacity to serve both the primary and remote coverage areas. However, these systems are usually bandwidth limited, so they can only support a limited number of radio channels. One issue with early repeaters was a lack of remote monitoring capability. Wireless service providers were unable to monitor performance and operational parameters to determine how the repeater was performing. Although these capabilities have been improved, it is still an issue with some repeater products.

Microcells provide additional coverage as well as capacity. Microcells were simply smaller versions of the full indoor cells (sometimes referred to as macrocells), often installed on telephone poles, or inside buildings. Although the microcells were much more compact, they generally provided much lower capacity. As a result, it was often necessary to add multiple microcells to an area to provide the required coverage and capacity. This was especially true for many in-building applications. In some cases, micocells were implemented with distributed antenna systems to provide greater coverage (e.g. antennas placed on multiple floors of a building). They were also implemented with cable that radiates low power radio frequency energy. Microcells have been used to provide coverage and capacity on major highways, in tunnels and inside buildings. For rural applications, tower mounted boosters were used to amplify both transmit and receive signals at the base station, and they were used with low power microcells to serve large coverage areas with a small, low capacity microcell base stations. This allowed operators to provide high power macrocell coverage using a more compact, low power microcell. While microcells provide a lower cost solution compared to conventional cells, the wireless operator still incurs many of the same installation costs. In particular, the costs to backhaul the microcell call traffic back to the mobile switching center can be much the same as it is for conventional cells.

The COW or Cell on Wheels was used to provide additional coverage and capacity during special events or temporary increases in capacity. These cells were essentially conventional cell sites that were mobile, and could be moved to different locations. These units were often configured by the wireless service provider using standard base station products from their equipment vendor. These units were effective in providing temporary coverage and capacity. However, they could be expensive to store and maintain. The COW could also introduce additional interference by transmitting on radio frequencies that were not typically used in the area on a regular basis.

Today's Remote RF Solutions

Today's remote RF systems include a myriad of microcell configurations, repeaters, fiber distribution systems, and Optical Wireless Technology. These systems are much more flexible than previous systems, in terms of the variety of products to choose from, the variety of sizes, and methods used to distribute RF signals. These systems also provide additional operations and management capabilities, as well.

Microcells come in many different sizes and configurations. Today's microcells can be mounted on poles to provide highway coverage, and wall mounted for in-building applications. Some microcells are modular and can be stacked or placed side by side, allowing service providers to install additional units as the capacity grows.

There are also a number of different shapes and sizes of base station antennas to compliment these microcells. In particular, there are a number of antennas for indoor applications that are very small and inconspicuous. Some of these antennas look more like lights or small sensors. Although the microcell units themselves are extremely flexible, it can still be a challenge to efficiently distribute radio frequency coverage throughout a building with multiple floors or a very large indoor area. As a result, a number of coverage distribution systems have been developed.

These systems distribute the radio signals from microcells to antennas that may be placed on different floors of a building or in other structures like sports arenas. Most of these systems are fiber-based systems that support multiple air interface technologies and high radio channel capacity. These systems take the RF signals from the microcell base stations and convert them to optical signals to distribute them to different areas. The optical signals are then converted back to RF signals and re-transmitted through a base station antenna. Depending on the particular system or application, single or multi-mode fiber may be used and coverage may be extended up to about 6 Kilometers. Other systems may also use Wavelength Division Multiplexing (WDM) technology, and longer range systems can extend coverage up to about 15 Kilometers. These systems are ideal for large office buildings with multiple floors, and other microcell applications that require coverage for large areas. However, they can be costly to implement. Fiber-based coverage extension products may also be used for other macrocell applications. These products provide a high capacity transport for blocks of radio frequency spectrum up to about 75 MHz. This makes them attractive for high capacity remote coverage scenarios where fiber can be utilized. These systems may also reduce the service provider’s deployment and recurring costs by reducing or eliminating the need for indoor equipment space and allowing the service provider to aggregate the backhaul from both the donor and remote sites.

Repeaters are still being utilized as well. Today’s repeaters are much more diverse in their configurations. There are a variety of models and manufacturers to choose from depending on the operating frequency, RF technology, and application. Although most repeaters have the capability to amplify the outgoing RF signals, there are also separate units (often called boosters) that can be used to increase the power level of the signals. These units can be used separately, or used with a regular repeater. It is also common for manufacturers to integrate the two functions into one system. Repeaters have also improved in terms of flexibility and operations and maintenance capabilities. Wireless service providers may now monitor the performance of these systems, along with the performance of their conventional cells. In some cases, they may also be able to integrate the performance data collected from their repeaters and their conventional cells. Today’s repeaters are a viable, low cost vehicle to extend wireless coverage. Repeaters are ideal for improving coverage in difficult areas that do not require an increase in capacity.

Recently, an innovative technology has also been made available to wireless service providers for remote RF applications. Optical Wireless transmission systems can also be used to distribute RF capacity to remote locations. These systems have traditionally been used for backhaul and data communications applications. Optical Wireless systems transmit signals using light waves like fiber optic cable systems. However, these systems transmit light wave signals from laser over the air. Like fiber optic cable, Optical Wireless systems may be used to transmit RF signals from a donor cell to a remote location. Optical Wireless Technology provides a high capacity alternative to fiber optic cable systems when it is not possible or practical to extend coverage and capacity via a fiber connection to a remote location. These systems can also be used in conjunction with other remote RF solutions such as repeaters and remote coverage distribution systems. In particular, this combination of technologies can be used effectively to provide in-building capacity and coverage for large buildings. While the use of lasers to transmit signals and information is not new, the application of this technology for remote RF products is a new concept.

Optical Wireless systems provide fast and easy deployment, and they transmit multiple channels simultaneously. Each channel can typically accommodate an RF bandwidth in the range of 15 to 20 MHz, and the channel bandwidth is scalable depending on the application, performance and capacity requirements. Multiple channels can be transmitted simultaneously, and the systems can accommodate any radio access technology. Unlike conventional radio frequency systems, Optical Wireless systems are not FCC (Federal Communications Commission) regulated. As a result, they can be deployed more quickly and more easily than conventional RF solutions such as microwave links. These systems are compact and they provide high capacity capability at a relatively low cost. Since they can facilitate the addition of both coverage and capacity, Optical Wireless systems can provide wireless service providers significant savings on cell site deployment costs. Furthermore, Optical Wireless Technology does not require RF transmissions between the remote and donor locations, and EMI (Electromagnetic Interference) is reduced. This may help wireless service providers deal with the safety concerns many people have about high frequency RF transmissions.

While remote RF systems have improved significantly over the years, the way in which they are used has not changed much. Therefore, the concept of utilizing remote RF technology to deploy cells across the entire network will be introduced here to utilize these systems to reduce the costs associated with the deployment of conventional cells. It is also suggested that Optical Wireless Technology is best suited for this application in dense urban environments.

Distribution of Centralized Radio Resources – A New Concept

Traditionally, wireless service providers have added capacity and coverage by adding new cells. As warranted by required capacity, coverage and a good business case, operators have continued to add new cells to build new networks and to expand existing ones. As the wireless industry has matured, it has become increasingly more difficult to acquire new cell site locations. As wireless networks continue to expand, the options for suitable cell site locations are decreased. Furthermore, it becomes more difficult to obtain the necessary zoning and required approvals for each site. The acquisition of new cell sites is also becoming more costly.

The traditional method of adding new cells inevitably leaves small areas of poor coverage and areas with insufficient capacity. Since subscriber traffic is not evenly distributed, it can be extremely difficult to provide sufficient capacity to all areas of the network. Dense urban areas present a difficult challenge with the need to penetrate buildings, parking garages and other structures. At times, it may be possible to resolve coverage and capacity problems with new cells. However, it is not always a good business decision to solve these problems with new cells. The revenue gained from the resolution of the problem may not offset the costs of cell site deployment and ongoing operational costs such as electricity, leasing costs and power. Figure 1 illustrates the traditional method of cell site deployment.

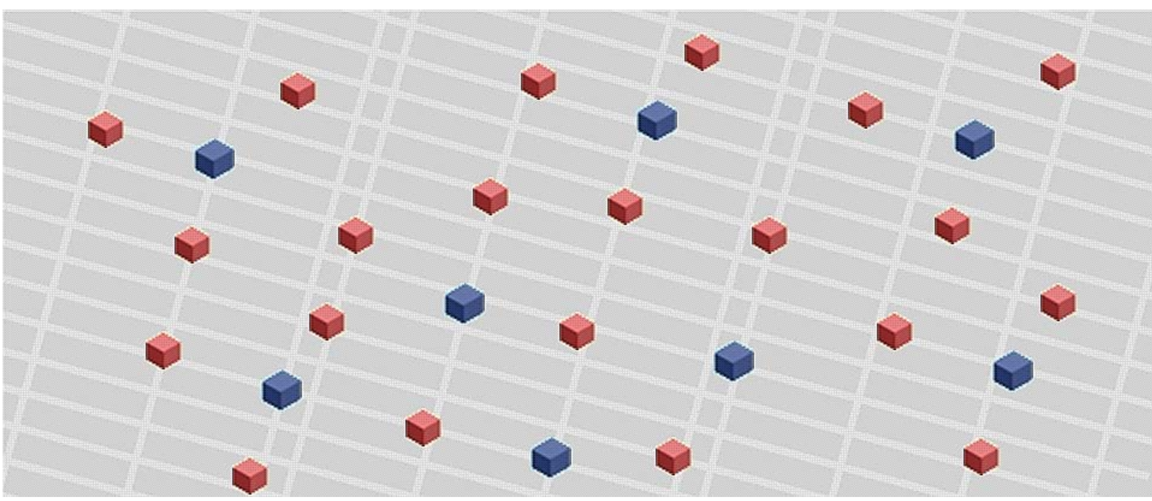


Illustration provided by Dabisoft

Figure 1 – Traditional Cell Site Deployment

Cell sites are deployed on a grid to provide coverage and mitigate interference from other cells. Cells shown in blue represent initial cell sites, and cells shown in red represent expansion cells that are added as the system grows and additional subscribers are added. This pattern is repeated as the network continues to grow. As the network continues to grow, it becomes increasingly more difficult to deploy cells on grid. The wireless industry has become much more competitive, and most major cities have at least four wireless service providers. As a result, wireless service providers must cost effectively expand their networks to stay competitive.

One method of reducing costs is sharing facilities between operators. This includes sharing of towers, leased building space, and even equipment between operators. Today, wireless service providers share space on towers for antennas, building space for permanent and temporary installations, backhaul facilities, and network equipment. Some operators are sharing switching facilities when it is not economical for one or both operators to purchase their own switching equipment. This trend is accelerating with escalating cell site deployment and operational costs. A number of countries in Europe and other parts of the world have established guidelines to extend sharing to include additional facilities and equipment. These guidelines have even established parameters for sharing antennas and base station equipment between operators. Wireless network equipment vendors are now manufacturing base station equipment that can be shared between operators.

In some cases, this cooperation between operators is mandated. Many large facilities like sports arenas refuse to provide separate facilities for every wireless service provider in a given market. As a result, common facilities are provided for wireless access and wireless service within the building. As an example, one room would be provided for all base station equipment, common antennas would be used to the extent possible, and backhaul facilities would be shared between operators. Any wireless operator that would like to provide service inside the facility would be required to utilize the common facilities provided for wireless access. Although cost sharing between operators is an effective method of cost reduction, additional methods of cost reduction are needed.

To further reduce the costs associated with deploying new cells, an alternative method of cell site deployment is introduced for consideration. Using today's remote RF technology, wireless operators can deploy or create hub cells to provide both centralized radio access and backhaul, to extend the capacity of the hub cells to remote locations. Using this method of centralizing cell site radio resources, wireless operators can use remote RF technology to extend coverage and capacity to various remote locations around a central hub cell. The hub cell would provide radio channel capacity to the central and remote locations. The remote locations could be connected to the hub cell via fiber, microwave or Optical Wireless links. Once the connection to the hub cell is made, the remote locations would only require the equipment necessary to establish the link to the hub cell and the RF antennas to provide coverage to the remote area. Using this deployment strategy, wireless service providers can significantly reduce the cost of adding capacity to the network. The deployment strategy is illustrated in figure 2.

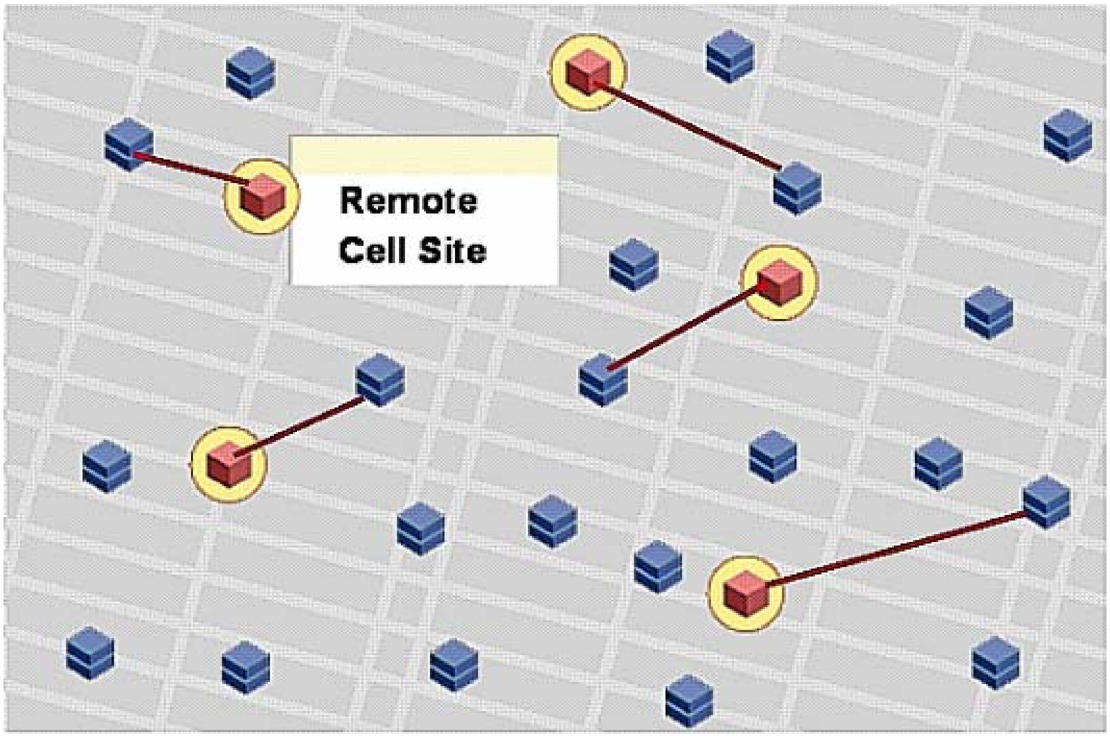
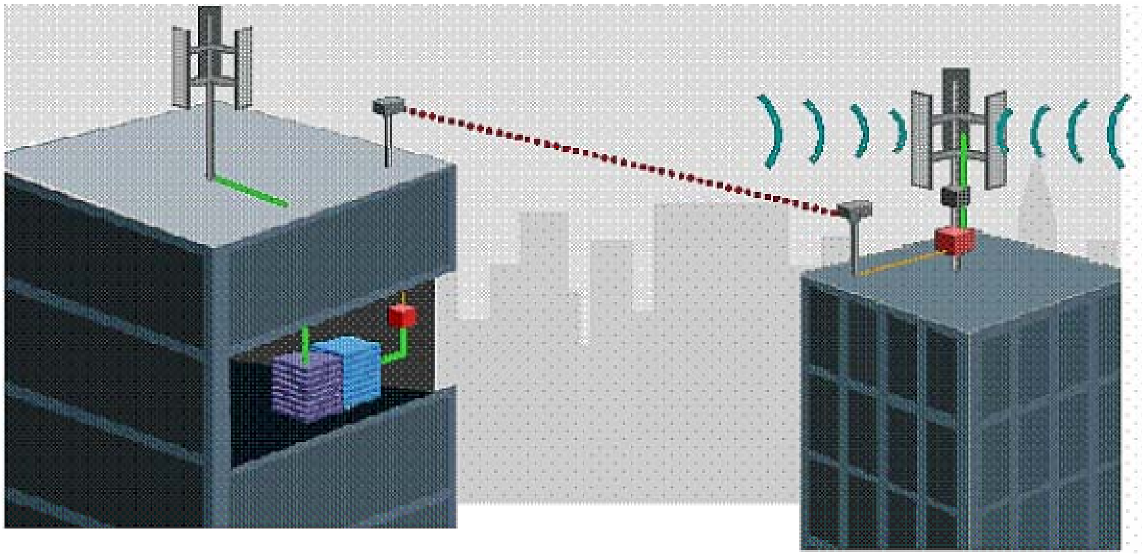


Illustration provided by Dabisoft

Figure 2 – Distributed Cell Site Deployment Using Remote Cells

As shown, traditional cells are shown in blue, and new remote cells are shown in red and highlighted. Donor cells are shown connecting to remote cells. A more detailed view of a single remote cell configuration, with its donor cell, is shown in figure 3.



Donor Cell **Remote Cell**

Illustration provided by Dabisoft

Figure 3 – A Single Remote Cell Shown With its Donor Cell

As shown, there is a virtual connection between the donor and remote cells. This connection would be a point to point connection (as shown) for a microwave or optical wireless link. If the connection were made using fiber optic cable, the cable would be located underground between the buildings.

Using today's remote RF technology, wireless operators can use this method of cell site deployment to significantly reduce costs associated with leasing building space, and providing power, electricity and air conditioning to cell site locations. A significant cost savings can also be achieved by aggregating the backhaul traffic from the hub cell and the remote locations. This method of distributing centralized radio resources is a cost effective and strategic method of cell site deployment that allows wireless operators to add capacity more rapidly. It also allows operators to add capacity and coverage to areas where it is difficult to acquire traditional cell site locations, and areas where it is not cost effective to deploy a traditional cell. This alternative method of cell site deployment may be used by wireless operators to build new networks, expand existing networks, and to deploy new radio access technologies, including next generation technologies for high speed wireless data. The benefits of cell site deployment using the distribution of centralized radio resources are listed below:

- Significant cost savings achieved by aggregating backhaul traffic for the hub and remote cells – hub provides shared backhaul facilities.
- Costs associated with leasing building space are significantly reduced, since indoor building space will not be required for most remote locations.
- Reduced deployment and operational costs associated with providing cell

site building facilities such as power, electricity, air conditioning, fire protection and security.
- Remote sites can be deployed much more quickly than traditional cell sites.
- Lower overall infrastructure installation costs resulting from base station co-location at hub cells.
- Lower maintenance and operating expenses due to base station co-location at hub cells.
- Enhanced deployment flexibility with remote cells.
- Lower overall deployment costs for new networks.
- Re-use of current cell site facilities for existing networks.
- Facilitates cost effective in-building coverage and capacity solutions.

This method of cell site deployment is even more powerful when it is combined with the sharing of facilities and equipment between wireless operators. Some or all of the remote RF technologies may be used to facilitate the distribution of centralized radio resources. It is further suggested that Optical Wireless Technology may be ideal for this application, for dense urban areas in particular. The equipment can be mounted on rooftops with the RF antennas, and there are no spectrum licensing requirements. It provides the capacity required for dense urban environments, and it is also easy to install and maintain. Optical Wireless Technology could help operators deploy cells much more quickly, which would improve their quality of service and customer satisfaction.

Wireless Network Deployment Using Remote RF Solutions

While it may not be possible or practical to consider using remote RF solutions to distribute centralized radio resources for every cell site deployment, it should be considered for use as a viable option for overall network build out or expansion. Given the potential benefits and cost savings, this technique is clearly not just for isolated cases. There are a number of applications for the use of remote RF technology to distribute centralized radio resources.

First, the distribution of centralized radio resources can be used to build out new networks. This method of cell site deployment would allow an operator to cost effectively implement donor and remote cell sites on grid, and then expand capacity with additional remote and conventional cells as required. This would provide a significant cost savings in backhaul costs and cell site deployment expenses. For existing networks, the same process could be used to provide incremental capacity increases by adding a combination of remote and conventional cells. The implementation of remote cells would reduce the number of conventional cells that would need to be added, and allow an operator to aggregate the backhaul traffic from donor and remote cells. In some cases, base station equipment could be moved from one cell location to another to create a new donor cell. The first cell would then become a remote cell and the operator would reduce costs by co-locating the base station equipment at another existing site and backhauling all of the traffic from one location.

Remote cells can also be deployed where additional capacity is needed and it is not economically feasible to install a conventional cell site. Implementation and installation of remote cells or sectors using remote RF technology is much easier to achieve. The use of remote cells and the distribution of centralized radio resources allow operators to provide capacity and coverage when and where they need it, in a fully scalable architecture.

Operators using CDMA technologies may also use remote RF technology to assist them with dynamic coverage and pilot pollution issues associated with these networks. As CDMA cell traffic increases, the coverage of the cell decreases. When this occurs with multiple cells in the same area, coverage holes can be created and there may not be a dominant cell to serve calls. This occurs when the power levels of CDMA pilot tones, which are used during CDMA handoffs, fluctuate rapidly. This causes rapid handoffs and more frequent dropped calls. Remote RF solutions can be used to provide coverage to areas where this phenomenon occurs.

The use of remote RF technology is ideal for dense urban areas. In particular, this technology can be used, along with the distribution of centralized radio resources, to provide in-building coverage. For these applications, optical technology can be used to distribute radio signals to antennas or radiating cable inside a building, or to utilize radio resources from another building. Both applications may be implemented simultaneously to provide in-building coverage more cost effectively. A remote RF solution can be implemented along with an in-building radio distribution system to provide in-building coverage to a remote location. This can be much more cost effective than installing new base station equipment and in-building radio distribution equipment in the remote location. New Optical Wireless Technology provides a very effective vehicle to transport radio signals from a donor site to a remote location.

In many urban cell site locations, more than one operator has equipment at the site. Some sites may have multiple wireless service providers operating from the same location. In some of these locations, operators share the antennas, cable and backhaul transport facilities. As the trend for sharing facilities and wireless equipment continues, optical technology will provide the capacity required to combine backhaul and other facilities for multiple operators. Operators can use all of these techniques and a variety of remote RF technologies to reduce the costs of network deployment. Overall, there is a compelling business case for the use of remote RF technology to build and expand wireless networks.

A Compelling Business Case

There are essentially three options to consider when evaluating RF technology to facilitate the implementation of remote cells. Microwave links, fiber optic cable and Optical Wireless Technology are the best options to implement a distributed cell site configuration. Donor and remote cells can be linked using any of these technologies to provide valuable cost savings.

When planning a new network deployment or the expansion of an existing network, wireless operators should consider these technologies to reduce the overall cost. The decision of which technology to use will be driven by capacity requirements, distance between donor and remote cells, cost, and implementation requirements. Any combination of these technologies may be used to connect donor and remote cells, and wireless operators may select the technology on a case by case basis.

Another consideration for wireless operators when evaluating these technologies is operations and maintenance capabilities. Although wireless network equipment vendors provide ample operations and maintenance capabilities, there may be some limitations with some individual remote RF solutions. Wireless operators should evaluate the operations and maintenance capabilities of each remote RF solution to insure that the limitations of that solution do not reduce their ability to monitor and evaluate the performance of each cell and the overall network. As operators evaluate remote RF solutions, they should determine the extent to which each solution can provide status and performance information on the link between donor and remote cells, and the extent to which it can operate with their existing operations and maintenance systems. The ability to integrate the two operations and maintenance systems is even more beneficial.

In general, fiber optic technology may provide the best solution for distributed cell site applications. Microwave systems do not provide as much capacity as fiber-based systems, and they can be difficult to implement in some locations due to scarce frequency resources, especially in the licensed frequency bands. In some areas, it can also be difficult to get approvals for high frequency microwave solutions. While they can be more time consuming to implement, fiber optic cable systems provide high capacity and allow the greatest distance between donor and remote cells. They can also be used to transfer narrowband voice and wideband data and voice signals. Optical Wireless Technology that is now being introduced can provide many of the same benefits as fiber optic cable. However, it can be implemented much more quickly and at a lower cost. This is a particular concern in urban areas, where dark, point to point fiber can be costly and difficult to deploy. Optical Wireless systems operate over unlicensed frequency bands, and they are very flexible in terms of deployment configurations. Like fiber optic cable systems, they can accommodate all wireless air interface technologies and they can transmit signals for more than one technology at a time. The limitation of these systems is their operating range as a function of the atmospheric conditions. To preserve a system availability of 99.999%, the operating distances are typically limited to 500 meters, which accounts for the expected worst case of scintillation effects and free space atmospheric conditions. In particular, dense fog can have a severe impact on link performance. Scintillation effects are essentially irradiance fluctuations and spatial intensity variations in the light beam at the receive aperture of the laser. As a result, these systems are best suited for dense urban applications, where the distances between donor and remote cells can be kept below 500 meters. In the event that good atmospheric conditions prevail in a given application (defined to be less than 60dB/km optical attenuation due to fog, light rain, etc.), the link distance may be increased beyond 500 meters while still preserving the 99.999% availability.

The ultimate choice of remote RF technology is left up to the operator. The compelling benefits of the use of this technology to distribute centralized radio resources are the potential reductions in capital and operating expenses, and the time required to deploy new cells. These reductions in expenses multiply as remote RF technology is used to proliferate remote cells throughout the network. Additional data from Northstream shows the per site savings that can be achieved with the implementation of remote cells. The remote cell costs per leased line site are shown in table 3, and the remote cell costs per microwave site are shown in table 4. In both tables, the cost of the base station equipment is highlighted. In both tables, it is assumed that the donor cell does not have any spare capacity, and it will be necessary to add a new base station for the remote cell. However, additional capital cost savings are obtained if the donor cell can provide the capacity for both cells. Both of these cases will be examined in the analysis of the cost savings data.

Two scenarios will be considered in the analysis of this data. The first scenario represents the worst case capacity situation, where the operator needs to purchase new base station equipment for the remote cell. The second scenario represents a coverage situation, where the operator can provide capacity for both the donor and remote cells at the donor site. In terms of capital cost savings, this is the best case scenario, since the operator would not need to purchase additional base station equipment.

Total costs savings data will be provided over a five year period. In addition, the NPV (Net Present Value) of the cost savings will be provided over the same time period, using an interest rate of 10 percent. The NPV of the cost savings may then be used to determine a reasonable price for a remote RF solution that would connect donor and remote cells.

Estimated savings and adjusted costs for a remote cell with leased line backhaul

All prices are in US$

CAPEX	Saving when using Remote RF Cell (%)	Explanation of assumption	Adjusted costs Year 1	Year 2	Year 3	Year 4	Year 5
NW planning	0%	No clear saving in network planning cost	5,500				
Site Acquisition *rooftop space* *indoor space*	10%	Only roof top space needed. However, savings on site acquisition are low as a similar level of effort is required to acquire roof top only.	4,500				
Civil works			9,216				
CW for indoor (BS room, etc)	80%	Only fitting of space for new equipment is required	6,696				
CW for rooftop (antenna, etc)	0%	Same effort required to put new antenna in place	2,520				
Leased line Connection	100%	Re-use of existing connection	0				
Site Support			4,500				
Antenna poles	0%	Need new antenna pole	500				
Power	100%	Re-use of existing connection	0				
Antenna line equipment	0%	Need new antenna line equipment	4,000				
Air-conditioning	100%	Re-use of existing A/C	0				
Fire/Security equipment	100%	Re-use of existing Fire/Security equipment	0				
BTS hardware and software	0%	Need new BTS	45,000				
Microwave link							
Total CAPEX			68,716				
OPEX							
Site Rent			2,250	2,250	2,250	2,250	2,250
rooftop space	0%	Need new roof space	2,250	2,250	2,250	2,250	2,250
indoor space	100%	Re-use of indoor space	0	0	0	0	0
Leased Line (2Mbps)	100%	Re-use of existing line	0	0	0	0	0
Electricity	90%	Minimal power consumption in new site	160	160	160	160	160
Microwave license fee							
Operations and Maintenance	50%	Estimated saving in O&M requirement	5,285	5,285	5,285	5,285	5,285
Municipal taxes	100%	No taxes on roof top space in Stockholm	0	0	0	0	0
Total OPEX			7,695	7,695	7,695	7,695	7,695
			Cost before savings:				
			22,670	22,490	22,315	22,146	21,982

Data provided by Northstream

Table 3 – Estimated Savings and Adjusted Costs per Leased Line Site

Estimated savings and adjusted costs for a remote cell with microwave backhaul

All prices are in US$

CAPEX	Saving when using Remote RF Cell (%)	Explanation of assumption	Adjusted costs Year 1	Year 2	Year 3	Year 4	Year 5
NW planning	0%	No clear saving in network planning cost	5,500				
Site Acquisition *rooftop space* *indoor space*	10%	Only roof top space needed. However, savings on site acquisition are low as a similar level of effort is required to acquire roof top only.	4,500				
Civil works			9,216				
CW for indoor (BS room, etc)	80%	Only fitting of space for new equipment is required	6,696				
CW for rooftop (antenna, etc)	0%	Same effort required to put new antenna in place	2,520				
Leased line Connection							
Site Support			4,500				
Antenna poles	0%	Need new antenna pole	500				
Power	100%	Re-use of existing connection	0				
Antenna line equipment	0%	Need new antenna line equipment	4,000				
Air-conditioning	100%	Re-use of existing A/C	0				
Fire/Security equipment	100%	Re-use of existing Fire/Security equipment	0				
BTS hardware and software	0%	Need new BTS	45,000				
Microwave link	100%	Re-use of existing microwave link	0				
Total CAPEX			68,716				
OPEX							
Site Rent			2,250	2,250	2,250	2,250	2,250
rooftop space	0%	Need new roof space	2,250	2,250	2,250	2,250	2,250
indoor space	100%	Re-use of indoor space	0	0	0	0	0
Leased Line (2Mbps)							
Electricity	90%	Minimal power consumption in new site	160	160	160	160	160
Microwave license fee	100%	Re-use of existing microwave link	0	0	0	0	0
Operations and Maintenance	50%	Estimated saving in O&M requirement	5,825	5,825	5,825	5,825	5,825
Municipal taxes	100%	No taxes on roof top space in Stockholm	0	0	0	0	0
Total OPEX			8,235	8,235	8,235	8,235	8,235
			Cost before savings:				
			17,850	17,850	17,850	17,850	17,850

Data provided by Northstream

Table 4 – Estimated Savings and Adjusted Costs per Microwave Site

As shown in tables 3 and 4, drastic reductions in capital and operating expenses may be obtained with the implementation of remote cells to distribute centralized radio resources. As compared to the conventional cell site implementation expenses shown in tables 1 and 2, remote cells can save wireless operators up to 40% on capital expenses, and as much as 60% on operating expenses, excluding the cost of a remote RF solution. It should be noted that the case shown in tables 3 and 4 assumes that a new base station is required at the donor cell. If this is not the case, additional capital cost savings could be obtained if radio equipment could be added to existing frames at the donor site. Both cases will now be examined from the standpoint of overall cost savings.

The first case is a high capacity scenario. This scenario assumes that it is necessary for the operator to purchase a new base station, and that the base station has heavy call traffic on all three sectors. For this scenario, the operator would also incur higher capital and operating expenses. This is essentially the worst case capacity scenario, which assumes that the operator could not use any radio resources from the donor cell, and the new cell is heavily loaded with call traffic. This capacity scenario assumes the following:

- The new base station is 3 sectors, and carries call traffic in excess of 50 erlangs per sector.
- The cost of the base station hardware and software is increased to $60,000 to account for multiple carriers on each sector.
- Increased call traffic for a high capacity cell increases the backhaul requirements to three leased lines, and three microwave links, respectively.
- Cost for leased line backhaul increases to $18,000 per year with the same 3% price erosion each year. Leased line connection cost increases to $3,600.
- Cost for microwave backhaul increases to $36,000, with $300 per year for licensing fees.

The adjusted capital and operating expenses for this high capacity scenario are shown in tables 5 and 6.

Adjusted costs for a high capacity cell site with leased line backhaul					
All prices are in US$	Year 1	Year 2	Year 3	Year 4	Year 5
CAPEX					
NW planning	5,500				
Site Acquisition	5,000				
rooftop space	1,000				
indoor space	4,000				
Civil works	36,000				
CW for indoor (BS room, etc)	33,480				
CW for rooftop (antenna, etc)	2,520				
Leased line Connection	3,600				
Site Support	13,000				
Antenna poles	500				
Power	6,500				
Antenna line equipment	4,000				
Air-conditioning	1,500				
Fire/Security equipment	500				
BTS hardware and software	60,000				
Microwave link					
Total CAPEX	123,100				
OPEX					
Site Rent	4,500	4,500	4,500	4,500	4,500
rooftop space	2,250	2,250	2,250	2,250	2,250
indoor space	2,250	2,250	2,250	2,250	2,250
Leased Line (2Mbps) - 3% annual price erosion assumed	18,000	17,460	16,936	15,887	15,410
Electricity	1,600	1,600	1,600	1,600	1,600
Microwave license fee					
Operations and Maintenance	10,570	10,570	10,570	10,570	10,570
Municipal taxes	0	0	0	0	0
Total OPEX	34,670	34,130	33,606	32,557	32,080
Total	**157,770**	**34,130**	**33,606**	**32,557**	**32,080**

Data provided by Northstream

Table 5 – Itemized Capital and Operating Costs for a High Capacity Leased Line Site

Adjusted costs for a high capacity cell with microwave backhaul					
All prices are in US$	Year 1	Year 2	Year 3	Year 4	Year 5
CAPEX					
NW planning	5,500				
Site Acquisition	5,000				
rooftop space	1,000				
indoor space	4,000				
Civil works	36,000				
CW for indoor (BS room, etc)	33,480				
CW for rooftop (antenna, etc)	2,520				
Leased line Connection					
Site Support	13,000				
Antenna poles	500				
Power	6,500				
Antenna line equipment	4,000				
Air-conditioning	1,500				
Fire/Security equipment	500				
BTS hardware and software	60,000				
Microwave link	36,000				
Total CAPEX	155,500				
OPEX					
Site Rent	4,500	4,500	4,500	4,500	4,500
rooftop space	2,250	2,250	2,250	2,250	2,250
indoor space	2,250	2,250	2,250	2,250	2,250
Leased Line (2Mbps)					
Electricity	1,600	1,600	1,600	1,600	1,600
Microwave license fee	300	300	300	300	300
Operations and Maintenance	11,650	11,650	11,650	11,650	11,650
Municipal taxes	0	0	0	0	0
Total OPEX	18,050	18,050	18,050	18,050	18,050
Total	**173,550**	**18,050**	**18,050**	**18,050**	**18,050**

Data provided by Northstream

Table 6 – Itemized Capital and Operating Costs for a High Capacity Microwave Backhaul Site

A summary of the capital and operating expense savings achieved by implementing a remote cell in lieu of a conventional cell for the capacity scenario is shown in table 7. This scenario assumes that the operator would need to purchase a new base station for the remote location, and the base station is heavily loaded with call traffic.

Cost Savings Summary	Capacity Scenario				
Cost Savings Summary per Leased Line Site					
Cost savings are in US$	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
CAPEX Savings	39,384				
OPEX Savings	26,975	26,435	25,911	24,862	24,385
Total	66,359	92,794	118,705	143,567	167,952
Total Savings					**167,952**
NPV of Savings					**120,672**
Cost Savings Summary per Microwave Site					
Cost savings are in US$	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
CAPEX Savings	71,784				
OPEX Savings	9,815	9,815	9,815	9,815	9,815
Total	81,599	91,414	101,229	111,044	120,859
Total Savings					**120,859**
NPV of Savings					**102,464**

Table 7 – Per Site Cost Savings – Capacity Scenario

Increased capital expense savings would be obtained if the operator could use radio resources from the donor cell to provide capacity to the remote cell. This is essentially a best case in terms of capital cost, since it assumes that the existing donor cell has sufficient radio resources to provide capacity for both the donor and remote cells. In this case, the operator would not have to purchase base station equipment or software. This is purely a coverage scenario. In this scenario, the capital expense savings is increased by eliminating the cost for a new base station in the first year. The conventional cell site costs for this scenario are the same costs from tables 1 and 2, with the cost for the base station eliminated. The cost savings achieved by implementing a remote cell in lieu of a conventional cell for the coverage scenario are summarized in table 8.

Cost Savings Summary	Coverage Scenario				
Cost Savings Summary per Leased Line Site					
Cost savings are in US$	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
CAPEX Savings	81,984				
OPEX Savings	14,975	14,795	14,620	14,451	14,287
Total	96,959	111,754	126,374	140,825	155,112
Total Savings					**155,112**
NPV of Savings					**130,097**
Cost Savings Summary per Microwave Site					
Cost savings are in US$	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
CAPEX Savings	92,784				
OPEX Savings	9,615	9,615	9,615	9,615	9,615
Total	102,399	112,014	121,629	131,244	140,859
Total Savings					**140,859**
NPV of Savings					**120,797**

Table 8 – Per Site Cost Savings – Coverage Scenario

These examples do not include the cost of the remote RF solution, since that would be dependent on the technology and the specific solution. However, an analysis of the escalating savings with the addition of new remote cells and an NPV (Net Present Value) analysis of the savings demonstrate that the cost savings would justify the purchases of the right remote RF solutions. As shown in figures 4 and 5, the realized cost savings increase significantly as additional remote sites are added in lieu of conventional cells. The cost savings in figure 4 and figure 5 reflect the cumulative capital and operating expenses saved over five years for each remote cell implemented in the capacity and coverage scenarios, respectively.

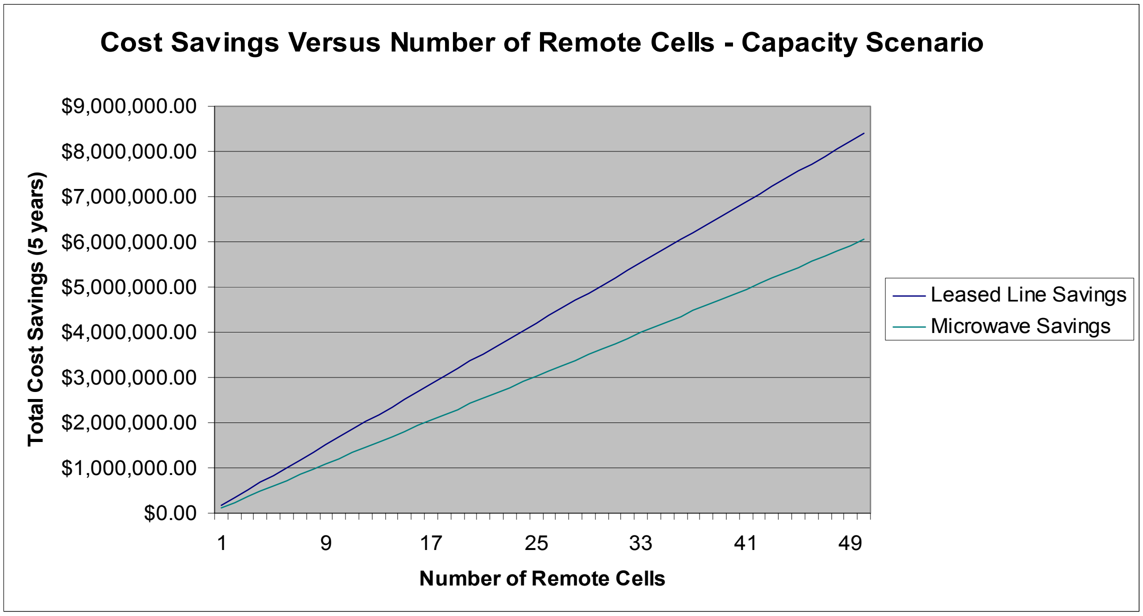


Figure 4 – Total Cost Savings as a Function of the Number of Remote Cells Capacity Scenario

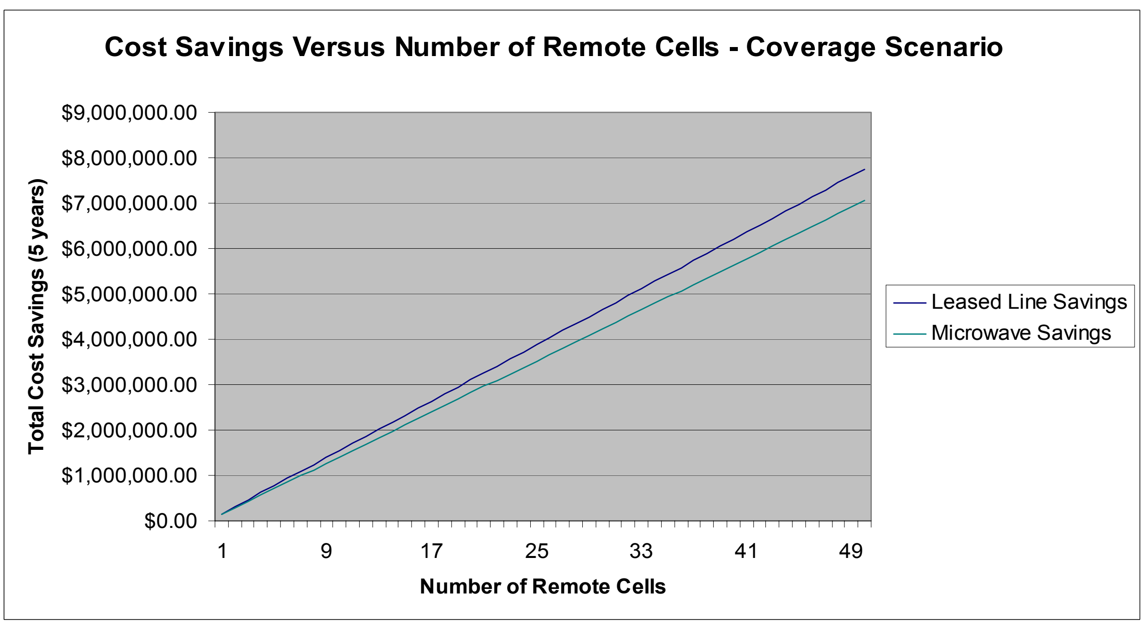


Figure 5 – Total Cost Savings as a Function of the Number of Remote Cells Coverage Scenario

An NPV analysis can be completed to show the net present value of the savings for one remote cell as compared to a conventional microwave or leased line cell. The NPV of the savings for each remote cell as compared to the two types of conventional cells is shown in Figures 6 and 7 for both the capacity and coverage scenarios.

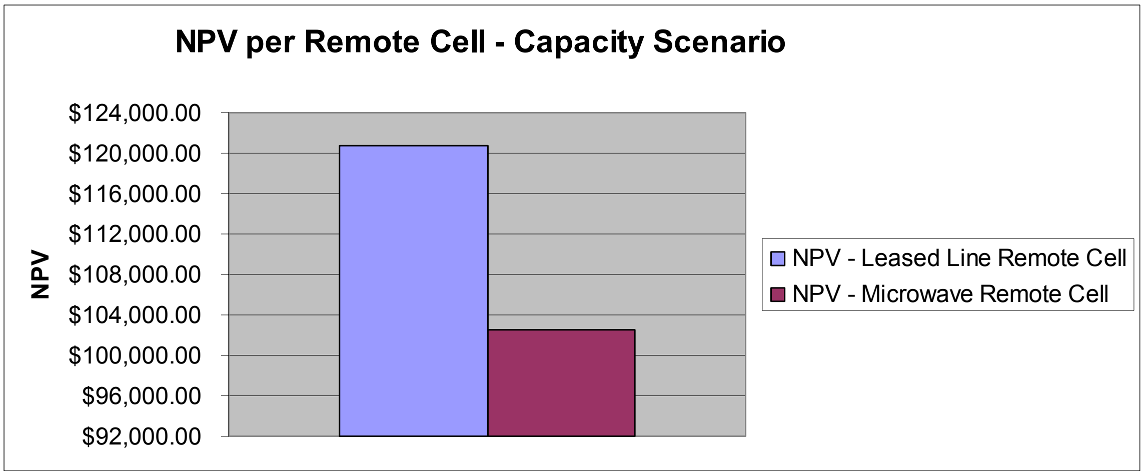


Figure 6 – NPV of cost savings per site – Capacity Scenario

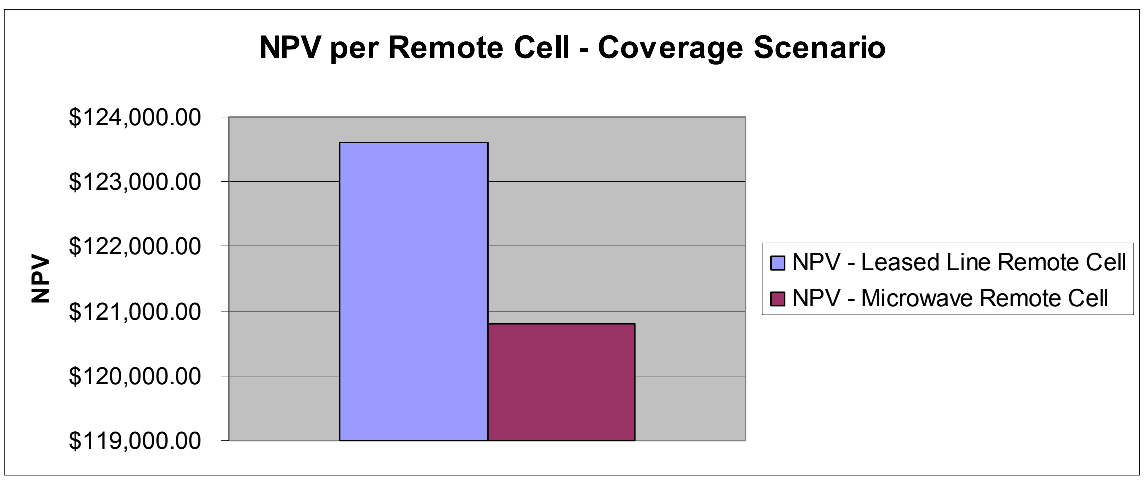


Figure 7 – NPV of cost savings per site – Coverage Scenario

As shown, the NPV of the savings is significant in both cases. However, the greater benefit is achieved when a remote cell is installed in lieu of a leased line cell. Since the NPV of the savings per remote cell scales linearly, the NPV of the savings increases significantly as remote cells are added. In figures 8 and 9, NPV is shown as a function of the number of remote cells implemented versus conventional leased line and microwave cells. The capacity scenario is shown in figure 8, and the coverage scenario is shown in figure 9.

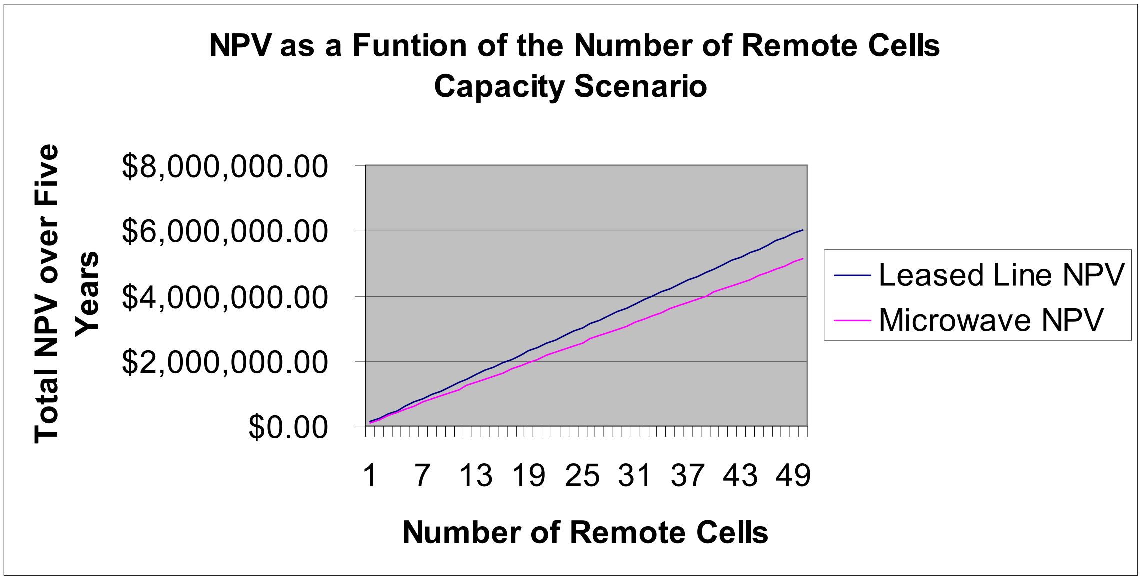


Figure 8 – NPV of Cost Savings per Remote Site – Capacity Scenario

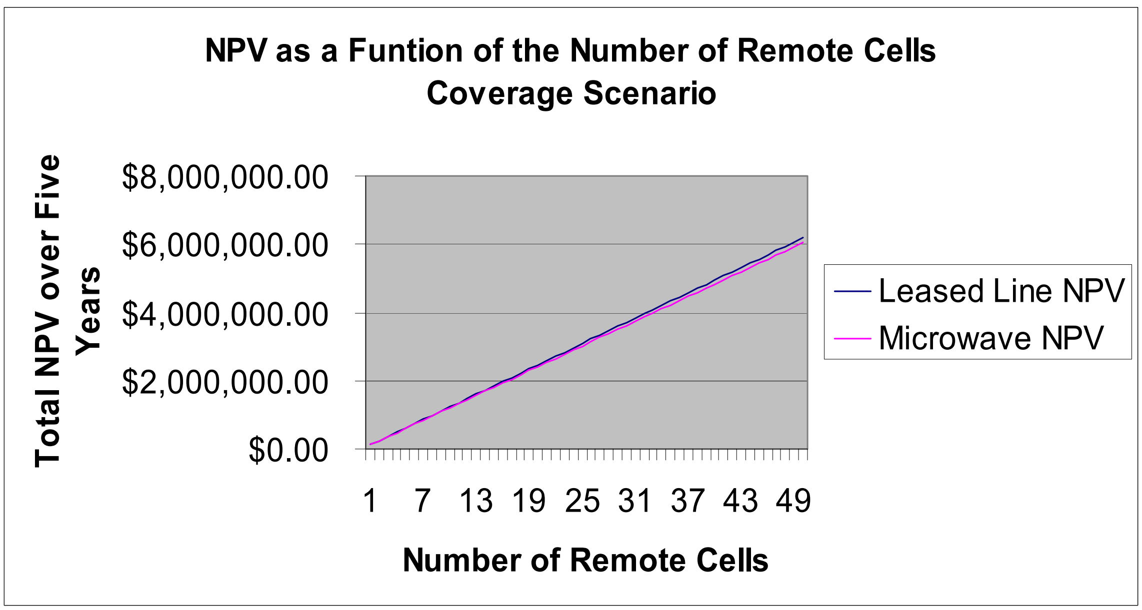


Figure 9 – NPV of Cost Savings per Remote Site – Coverage Scenario

An additional financial benefit may obtained by wireless operators when they implement remote cells. Since remote cells can generally be implemented more quickly, operators obtain additional revenue from remote cells that are deployed faster than conventional cells. The amount of time required to install a remote cell will depend on the technology selected and the specific solution. However, the estimated net revenue generated from a new cell in an urban environment is about $50,000 per month. This figure can be used to estimate the additional revenue that would be obtained, based on the reduced deployment time for a remote cell.

This and other data can be used by wireless operators to determine if a particular remote RF solution is a good solution from a financial standpoint. With the cost of the a specific remote RF solution, and a detailed analysis of the investment required and the subsequent cost savings, operators can evaluate which solution makes the best sense financially. From the NPV analysis of the cost savings for a new remote cell, it was determined that the NPV of the savings ranged from a minimum value of $102,464 for a microwave remote cell in a high capacity scenario to a maximum value of $130,097 for a leased line remote cell in a coverage scenario. Based on these figures, a cost of $75,000 would be justified for even the worst case scenario of cost savings. A cost of $50,000 would make the proposition of remote cells even more attractive. As a result, a price in the range of $50,000 is proposed as a reasonable price for a remote RF solution, given the cost savings it would provide. As shown in the cost savings summary, the remote RF solution would be paid for in less than one year in all scenarios. If a new remote cell generates $50,000 per month in net revenue and it can be deployed at least one month sooner than a conventional cell, the remote RF solution could be paid for in as little as one month. Of course, the business proposition becomes even more attractive as the price of the remote RF solution decreases. Now that a target price range has been determined, several other factors should also be examined when evaluating a remote RF solution to facilitate the implementation of remote cells.

As a part of the evaluation of a remote RF solution, operators should consider the time required to deploy the solution. Rapid deployment leads to a lower time to profit for the wireless operator. Operators should also consider how easily the remote RF solution can be re-deployed. The extent to which a solution can be easily moved to different locations within the network would add additional value to the solution for the operator.

Although the results of each operator's analysis will vary based on their geographic location and their expenses for conventional cell sites, this preliminary data provides evidence that wireless operators have a tremendous opportunity to reduce their overall cell site deployment costs. This makes a strong business case for the use of remote RF technology to distribute centralized radio resources whenever possible.

Conclusion

Remote RF solutions have evolved as wireless network infrastructure has evolved. A variety of remote RF solutions exist today to help operators provide improved capacity and coverage. These solutions can be implemented individually or in tandem to achieve the desired results. Optical Wireless Technology is viable option for remote RF applications in urban environments.

Wireless operators can generate tremendous cost savings by utilizing remote RF technology to distribute centralized radio resources. The operator's savings are increased significantly as an increasing number of remote cells are added in lieu of conventional cells. The implementation of remote cells provides reductions in both the capital and operating expenses associated with new cell site deployment. Wireless operators should consider the implementation of remote cells as a part of their overall network deployment, expansion of their existing network, or for the implementation of new wireless access technologies. As the evolution of wireless equipment continues, our processes for its implementation must also evolve.

Acknowledgements

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