The Effect of Cellular Service on the Cost Structure of a Land-Based Telephone Network

by David Gabel and D. Mark Kennet

Columbia Institute for Tele-Information
Graduate School of Business
Columbia University
809 Uris Hall
New York, NY 10027
(212)854-4222

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David Gabel
Queens College

and

D. Mark Kennet
Bureau of Labor Statistics

PRELIMINARY -- DO NOT QUOTE OR CITE
SEPTEMBER 9, 1996

Abstract: While economies of scale and scope have been extensively studied in traditional telephone networks, thus far little academic attention has been paid to the effect of cellular communications, which is one of the most rapidly growing segments of the telecommunications system. We use LECOM – our Local Exchange Cost Optimization Model – to generate data representing an optimal telephone network before and after the introduction of a cellular network. We derive geographic data from Statistics New Zealand's meshblock data. Our cost data for network components are "typical" North American annual costs.. Our initial results suggest, somewhat intriguingly, that there may be potential gains to more widespread introduction of cells in some rural areas, particularly those characterized by customer populations clustered along major roads.

INTRODUCTION.

LECOM, the Local Exchange Cost Optimization Model, has been in service since 1991 when it was first developed by under a grant from the National Regulatory Research Institute of Ohio State University. LECOM operates by optimizing a telephone network on a map by choosing the technology mix, number of facilities, and locations of the facilities within the area that minimize the annualized cost of service. The software has (so far) been at the core of three published articles (Gabel and Kennet (1993a), Gabel and Kennet (1993b), and Gabel and Kennet (1994)), a published research monograph (Gabel and Kennet (1991)), and at least three scholarly presentations or works in progress (Kennet and Gabel (1995), Kennet, Heyen and Gabel (1995) and Gasmi and Sharkey (1995)).

The original version of the software, which is in the public domain, could be used to determine the economic crossover point between different type of wireline facilities (e.g., copper, digital line carrier on copper, or digital line carrier on fiber). The new version of the software identifies the economic crossover point between landline and wireless networks. The model takes into account the high usage costs but low customer access costs of wireless technology, and explores the economic trade-off with the high customer access/low variable cost structure of wire networks.

While economies of scale and scope have been extensively studied in traditional telephone networks, thus far little academic attention has been paid to the effect of cellular communications, which is one of the most rapidly growing segments of the telecommunications system. We use LECOM to generate data representing an optimal telephone network before and after the introduction of a cellular network. We derive geographic data from Statistics New Zealand's meshblock data. Our cost data for network components are "typical" North American annual costs. Our initial results suggest, somewhat intriguingly, that there may be potential gains to more widespread introduction of cells in some rural areas, particularly those characterized by customer populations clustered along major roads.

The paper is organized as follows. In Section I, we briefly describe the LECOM model for a land-based exchange network. In Section II, we describe how we incorporate a model of cellular telephony into LECOM. Finally, in Section III we give our results for New Zealand and provide some discussion.

I. THE LECOM OPTIMIZATION MODEL AND ITS DATA REQUIREMENTS

There are three primary types of facilities found in the local exchange carrier's network: the local loop, switching, and trunking. The local loop is composed of facilities that provide a signaling and voice transmission path between a central office and the customer's station. The central office (or wire center) houses the switching machine that connects a customer's line to either another customer who is served by the same switch, or to an interoffice trunk. Calls between central offices are carried on trunks.

LECOM operates by first determining an area's dimensions and customer usage levels from user data. LECOM then searches for the technological mix, capacity, and location of switches that minimize the annual cost of production. This is equivalent to minimizing the present worth of capital, maintenance and tax expenditures (see Freidenfelds (1978)). The locations of the switches are optimized by the nonlinear derivative free routine proposed by Nelder and Mead (1965).

The cost optimization is based on the cost of various technologies that are currently available to local exchange carriers. See Gabel and Kennet (1991), (1994) for details.

Local Loop Topology

Telephone engineers break the service territory of a central office into discrete regions, called serving areas. Since the early 1970s, serving areas have been the basic building block used to determine the most economical choice of facilities.[1] The facilities that compose the serving area are commonly referred to as the distribution plant. A serving area typically includes 350 to 600 subscribers. Feeder plant connects the service area to the central office. In turn, distribution plant connects the feeder plant to the subscriber, and is often referred to as the distribution plant.

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[1]Bell Telephone Laboratories, *Telecommunications Transmission Engineering: Networks and Services* (2nd edition), 40-44; and John Freidenfelds, *Capacity Expansion: Analysis of Simple Models with Applications* (New York, North Holland, 1981) 238.

Figure I depicts a typical serving area. A backbone cable runs from the serving area interface and street cables--or legs--branch off the backbone at equal intervals. Each time street cables branch off, the backbone cable tapers down.[2]

The same design principle is used with feeder plant. Feeder cable runs from the central office and is connected to a number of branch feeder cables. This design, known as the "pine tree geometry," minimizes the cost of outside plant facilities.[3]

Consistent with engineering practices, we have assumed that the main feeder cables leave the wire center in four directions.[4]

Interoffice Traffic

Exchange traffic either may originate and terminate on the same switch (intraoffice traffic), or go between central offices (interoffice traffic). As shown in Table I, the proportion of calls that originate and terminate on the same switch varies between communities. In rural areas, all customers in an exchange typically are served by one switch. Consequently, interoffice exchange calls from small towns occur only where extended area service has been established.

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[2]J. A. Stiles, "Economic Design of Distribution Cable Networks," *Bell System Technical Journal* 57 (April 1978): 945.

[3]Bell Laboratories, *Telecommunications Transmission Engineering*, 62. The use of the pine-tree topology provides an approximately 5 to 30 percent saving over a bush architecture.

[4]Bridger M. Mitchell, "Incremental Costs of Telephone Access and Local Use," Rand R-3909-ICTF (July 1990), 17.

Table I

Intraoffice Calls: Proportion of Total Calls

Community	Percent
Rural	66
Suburban	54
Urban	31

Source: R.F. Rey, ed., Engineering Operations in the Bell System (Murray Hill, N.J.: Bell Laboratories, 1983, second edition), 125.

In larger cities, the local exchange company typically deploys more than one switch. Suburban customers are less likely than urban customers to place an interoffice call because their primary community of interest is in nearby stores and among neighbors, locations often served by the same switch. Urban customers, on the other hand, are more likely to need to call customers served by a different switch.

Traffic studies show that when an interoffice call is placed, there is a greater likelihood that it will be placed to a customer served by a nearby switch rather than a distant machine. For example, a subscriber placing an interoffice call from downtown is more likely to call another downtown customer than a suburban subscriber.

We have constructed LECOM to take into account business customers being more likely to place interoffice calls that mostly go to nearby switches. The percent of intraoffice calls is an increasing function of the number of customers terminated on the customer's host switch divided by the number of switched customers in the city.

Switching

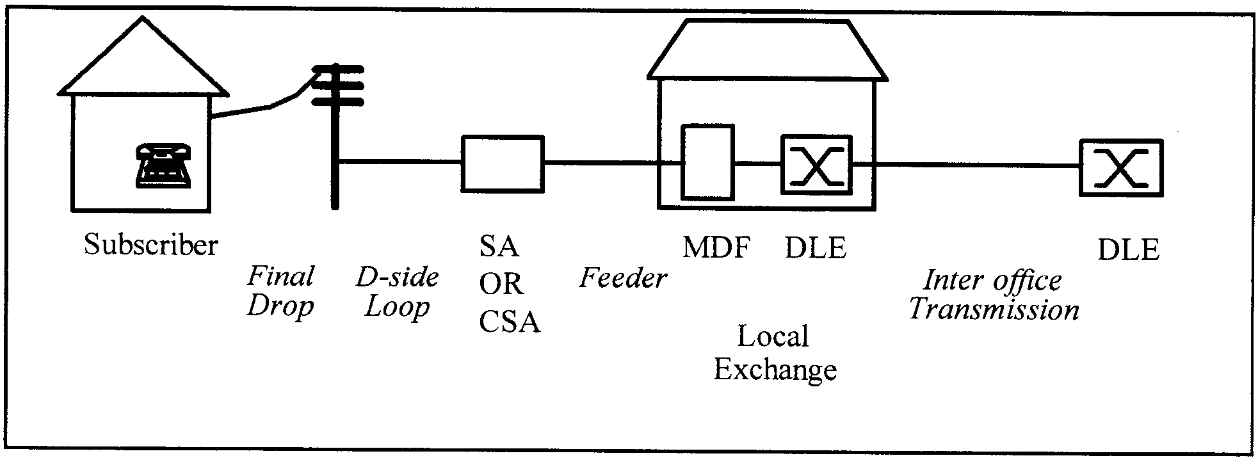
A number of companies manufacture digital switching machines. We have modeled the network using switches manufactured by Northern Telecom. The capacity of these switches has grown greatly in the past decade.

Cost Structure of Wireline Network

A. The Local Loop

A total service or total element cost study is designed to evaluate the costs of providing a single service or group of services by determining the costs that are no longer incurred when the service or services are not provided. In a wireline network there are three primary types of facilities: the local loop; switching; and, trunking. The local loop is composed of facilities which provide a signaling and transmission path between a central office and the customer's station. The central office (or wire center) houses the switching machine that connects a customer's line to either another customer, who is served by the same switch, or to an interoffice trunk to another switch. Calls between central offices are carried on trunks (see Figure II below).

Figure II: Components of the Typical Access Network



CSA= Carrier Serving Area

D-side = Distribution Side

DLE = Digital Local Exchange

MDF = Main Distribution Frame

SA = Serving Area

The largest part of the investment made by a local service network operator is for its local loop facilities. Within the local loop there are certain fixed costs associated with laying cables which are independent of the capacity of the cable, that is the number of pairs of cable in the cable sheath (see Column C in Table II below). Within each cable sheath, there is a variable cost component that is a function of the number of customers being served (see Column B in Table II below).

An incremental cost study measures the change in cost which is associated with the change in the level of demand. When estimating the change in loop costs, the appropriate economic question that needs to be addressed is whether or not there would be a different number of cables if the level of demand were to grow. If the answer to this question is affirmative, then the estimate of the change in loop costs should include the change in fixed costs associated with laying cables (i.e., site preparation and excavation, leases, etc.). If the answer is negative, the estimate of the change in loop costs should reflect only the cost of using the same number of cables but with greater capacity, that is different size cables, not additional cables, and should not reflect any change in the fixed costs of laying cables.

These cables that connect customers to the central office are costly to install, largely because of the labor cost of installing the facilities. Table II identifies the expense of installing 100 meters of aerial cable.[5] By law, buried cable is mandated in New Zealand. I am presenting data for aerial cable because it illustrates the cost structure of installing cable. The same cost structure exists for buried and underground cables.

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[5] Rebuttal Testimony of Kenneth P. Helgeson, p. 13, Director of Engineering and Construction, NYNEX, evidence submitted to the Maine Public Utilities Commission, January 13, 1995, Docket 94-123/94-254. The data in Table II only include the investment in the aerial cable--the cost of the pole is not included. An exchange rate of $1.51 NZ/$1 US was used to develop the table.

Table II assumes 100% utilization, a fill level that is not achieved in practice. Typically utilization runs around 65% and, therefore, if utilization were taken into account the average and incremental costs would be higher by a magnitude of 1/.65 = 1.53. The incremental investment per pair is derived by dividing the additional cost of a larger cable by the change in the size of the cable.

Table II: Investment Per 100 Meters of Aerial Copper Cable

Investment Per 100 Meters (NZ $)					
Cable Size # pairs per sheath (A)	Material (cable) (B)	Installation (C)	Equipped, Furnished, and Installed (D) = (B) +(C)	Average Investment Per Pair (E) = (D) / (A)	Incremental Investment per Pair (F)
100	$272.83	$378.94	$651.77	$6.52	$6.52
200	$510.30	$378.94	$889.24	$4.45	$2.37
300	$752.82	$378.94	$1,131.76	$3.77	$2.43
400	$1,000.39	$378.94	$1,379.33	$3.45	$2.48

While the number of observations in the table is small, it is representative and can still be easily summarized with linear regression analysis:

$$\text{Investment} = \beta_1 + \beta_2 * \text{Cable\_Size} + u$$

$$= 406.72 + 2.43 * \text{Cable\_Size}$$

The ordinary least estimate of β_1, NZ$406.72, is the estimate of the fixed investment cost of installing 100 meters of aerial cable. The slope term, β_2, NZ$2.43, is the estimate of the incremental investment cost of installing one additional pair of cable, 100 meters in length.

The capacity of a copper cable runs up to 4,200 pairs. The fixed cost of the cable is only part of the TSLRIC of residential service if either of the following two conditions hold true: (1) there are no business customers sharing the cable; or (2) the number of customers served in an area is greater than 4,200 pairs, and the elimination of the residential customers reduces the number of cables that must be installed.[6]

[6] If fiber cable is being used in the feeder plant, it is unlikely that the elimination of residential customers will change the number of fiber cables that are deployed (due to the high capacity of the fiber cable).

B. The Local Switching Machine and Electronics in the Local Loop

In the previous section, I addressed the economics of deploying copper cable to connect customers to the central office. Other facilities used in wireline networks are typically less labor intensive, but they nevertheless involve substantial fixed costs. For example, when a digital switch is deployed, a sizable fixed cost is incurred. In order to run a digital switch, the local service network operator must incur certain start-up costs, for example the central processor and associated software required for "plain old telephone service" (POTS), as well as certain maintenance and test equipment expenses. These start-up costs are included in the estimate of the change in costs when the addition of residential customers increases the number of switching machines.

When fiber optics are deployed in the loop, there are also significant start-up costs that may not be part of the TSLRIC of residential service. The data in Table III assume that there are 1,000 customers at the remote site which houses the electronics.[7]

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[7] The investment and capacity data was obtained from New England Telephone, Maine Marginal Cost Study, Docket 92-130, Part 3, Tab A, Section IV, Table 2.1. Aerial cable was used in the Maine Marginal Cost Study.

Table III: Residential Fiber Optic Start-Up Costs

Fiber Optics in the Loop (NZ $)				
Equipment (a)	Investment (b)	Voice Channel Capacity (c)	Average Investment (1,000 subscribers) (d)= (b)/(c)	Incremental Investment (e)
Digital Line Network operator	$16,872	96	175.75	175.75
Mux	27,892.5	3,528	27.89	0
Site	62,670	3,528	62.67	0
Total			$276.15[8]	$175.75

The mux and site costs are part of the TSLRIC of residential service when additional facilities are required in order to serve the additional residential customers. The digital line network operator cost is a part of the TSLRIC of residence regardless of whether equipment is shared with business customers. Due to the small capacity of the equipment, the cost is incurred at the margin and therefore is part of the cost of serving residential customers.

C. Interoffice Facilities

Even more so than the local loop, fiber optic cables are deployed in the interoffice network. The fiber optic cables provide suppliers with a flexible medium that allows the suppliers to easily expand capacity to meet the demand of its customers. The cost of deploying fiber cables is not dissimilar to the cost of installing copper cables. Material costs can constitute a small portion of the cost of installing cables. Since the process is labor intensive, the majority of the cost can be associated with capitalized labor time. Pacific Bell and GTE of California estimate that cable costs constitute only one-fifth the

[8] The sum of the average investment for digital line network operator, the mux, and the site does not equal the average cost per subscriber because of the integer problem--1,000 customers would require round(1000/96 + .5) = 11 units, and this raises the average investment per subscriber slightly. If not for this integer restriction, the sum of column (d) would be $266.31. Hence the difference between incremental and average cost is largely due to fixed investments, rather than the integer restriction.

cost of installing cables.[9] The multiplexers on interoffice facilities, like those used for local loops, provide flexible amounts of capacity depending on the speed of the multiplexer and the extent to which the equipment is fully loaded with boards that are used to accelerate the speed of the digital signals.

D. Summary Comment regarding the cost structure of wireline networks

There are very few customer-specific investments on a wireline network. Except for the line card on a digital switch, and the pair of wires that are dedicated to a subscriber, there are few facilities that are not shared by multiple customers.

The first cost of the line card varies greatly depending on the manufacturer of the switch. In this study we are estimating costs using a version of LECOM that models that assumes that only Northern Telecom switches are deployed on a wireline network. The cost of terminating a line on a Northern Telecom switch is high relative to other digital switches.

The first cost of the pair of wires that provide access to the network is a function of customer density and the length of the loop. The cost of the wire has elements of both a direct and shared cost. The cost of the pair of wires is directly attributable to the subscriber. On the other hand, the capitalized labor installation cost is a shared cost that may or may not be independent of an individual customer connecting to the network. To the extent that capacity is exhausted in a cable, the capitalized labor cost is directly attributable to individual subscribers. However, where there is no congestion, the installation cost is only part of the incremental cost of service when the entire demand for loops is considered (as with total element long-run incremental costs).

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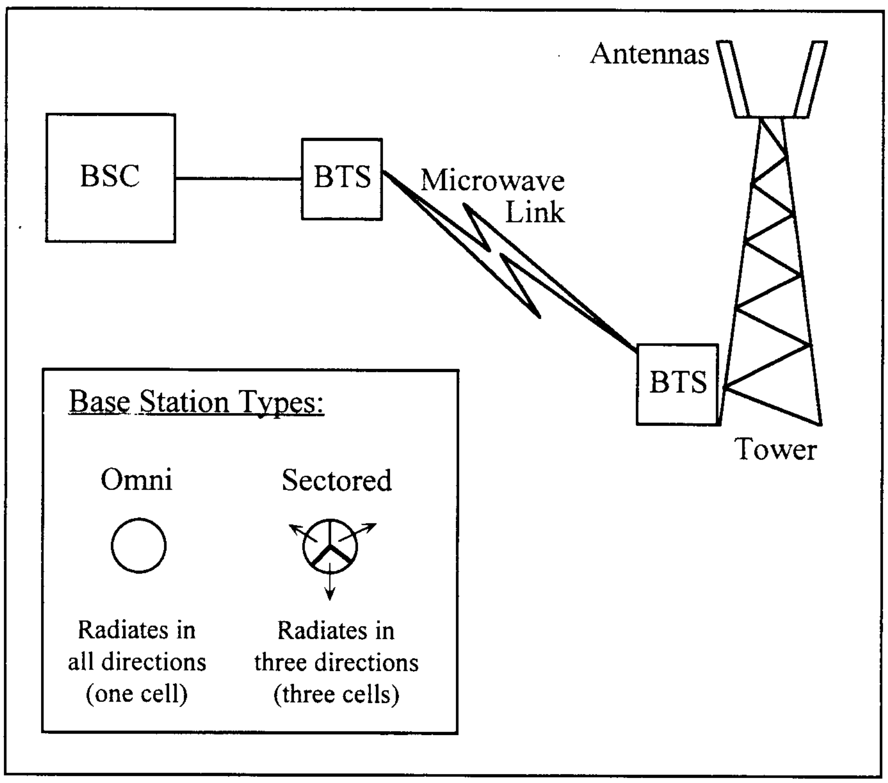
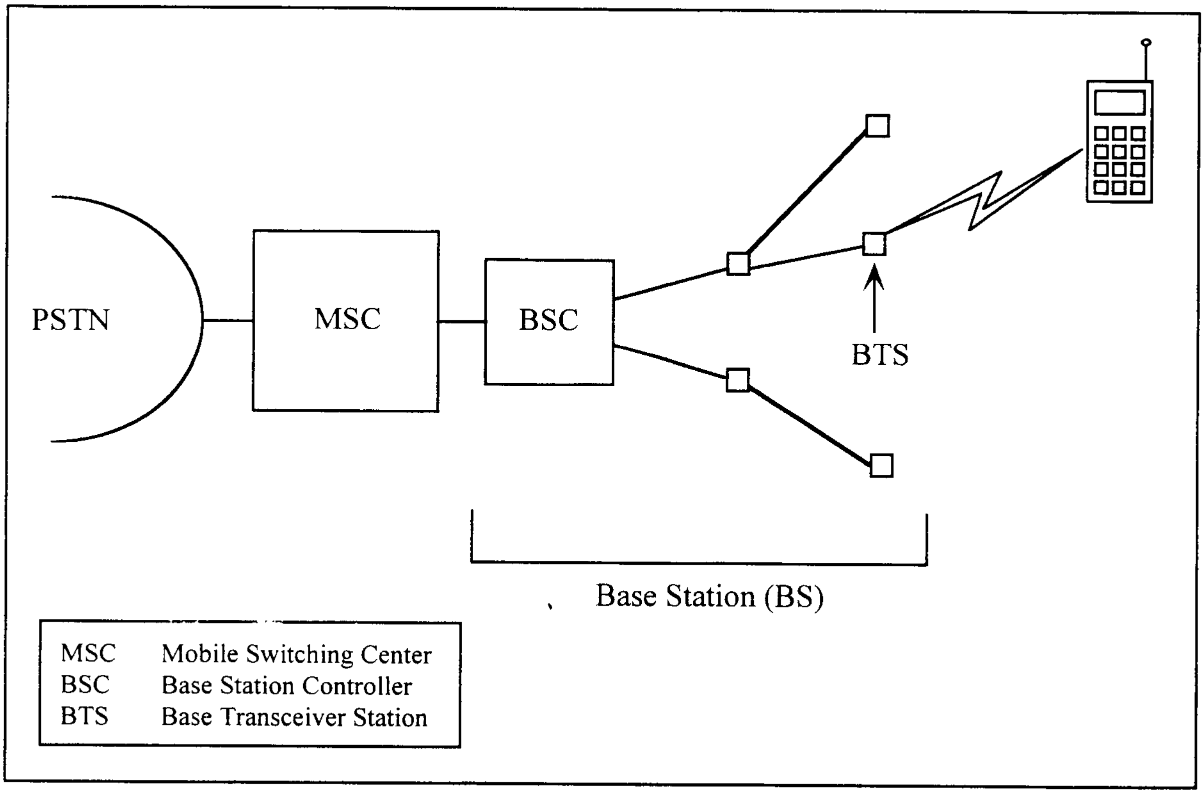
[9] Timothy Tardiff, "Economic Evaluation of Version 2.2 of the Hatfield Model," NERA, July 9, 1996, prepared for GTE in Rulemaking on the Commission's Own Motion to Govern Open Access to Bottleneck Services and Establish a Framework for Network Architecture Development of Dominant Carrier Networks," California Public Utilities Commission, R.93-04-003, p.6. The data presented in Table 1 suggest that the material component is larger than twenty percent. The difference in percentages may be explained in part by the use of buried cable in California. Installing buried cable is relatively more labor intensive than hanging aerial cable on poles.

II. Incorporating Wireless Stations into LECOM

We know turn to a description of wireless network technology. By wireless we mean the ability to secure two-way communications at a distance without the use of wires. Figure III illustrates the equipment that is involved in a wireless network.

Figure III: Radio Base Station





We are interested in modeling the cost of using wireless network to serve areas that are expensive to serve using traditional wireline facilities. Therefore we have modeled a fixed mobile network. In a fixed mobile network, a wireless network is used to connect the wiring in a household with a switching machine. Within the household, a traditional handset can be used. An antenna on the dwelling structure transmits and receives radio signals with the closest base transceiver station.

In a GSM network, base station transceivers (BTS) are located approximately 20 to 30 kilometers apart. Ulysses Black provides the following description of the equipment required for a GSM network:[10]

> The interface with the mobile station (MS) is provided through the base transceiver station (BTS). These two components operate with a range of radio channels across an air interface. The BTSs are controlled by the base station controller (BSC), which is a new cellular network element that was introduced by GSM. It is responsible for the hand over

[10] *Emerging Communications Technologies*, Prentice Hall 1994 (pp. 344-345).

operations of the calls as well as for controlling the power signals between the BTSs and MS--thus relieving the switching center of several tasks.

The mobile MSC is the heart of the GSM and is responsible for setting up, managing, and clearing connections as well as routing the calls to the proper cell. It provides the interface to the telephone system as well as provisioning for charging and accounting services.

GSM requires the use of two databases called the home location register (HLR) and visitor location register (VLR). These databases store information about each GSM subscriber. The HLR provides information on the user, its home subscription base, and the supplementary services provided. The VLR stores information about subscribers in a particular area. It contains information on whether mobile stations are switched on or off, and if any of the supplementary services have been activated or deactivated.

In LECOM, we have modeled the tower locations as an argument to the cost function, with the Base Station and MSC centrally located. Serving areas are "attached" to the tower according to a binary function: cost of attachment is zero if the entire serving area is within 15 km (Cartesian distance, rather than rectangular distance) of the tower, machine infinity otherwise. Thus, the tower becomes a technology alternative to the host-remote configuration previously modeled in LECOM. We have assumed that each region modeled has its own MSC. For the purposes of this exercise, we have further assumed that all interoffice traffic is carried by microwave.

Cost Data for Wireless Network

The equipment required at the customer's location is quite expensive. In a recent study undertaken for AT&T and MCI, Hatfield Associates and Economics and Technology suggest that the investment is approximately US$300 per household. Because of this expensive item, they conclude that "[a]t this level, it is evident that cellular radio is an unlikely replacement for the existing LEC telephone service."[11] While

[11] *The Enduring Local Bottleneck: Monopoly Power and the Local Exchange Carriers*, Economics and Technology and Hatfield Associates, 1994, p.91. A similar conclusion has been reached by Prudential Securities: "While we don't believe wireless will develop into a substitute for wireline access, it should complement the rapid growth and development of wireline networks." Prudential does believe though that in rural

we find the assumption of a $300 investment per household to be reasonable, the purposes of this paper is to evaluate the cost savings associated with using a fixed mobile network. As we show below, despite the assumption of a large customer specific investment, we still find that fixed mobile technology provides savings relative to a wireline only network.

The antenna on the customer's household communicates with the nearby base transceiver station. The cost structure of the base transceiver station is quite different than that of the loop plant for a wireline network. The cost of serving a customer on the wireline network is very much affected by the distance between the customer and the central office. Distance is still important on a wireless network; the farther a customer is from a central office the more equipment is required for transmitting the call from the BTS to the MSC. This distance sensitivity for the wireless technology is not unlike the distance sensitivity for the feeder portion of a wireline network.

There are two important distinctions though between the wireline and wireless network. First, the cost of the link between the household and the BTS is independent of distance. It does not matter if the customer is located one or eleven kilometers from the BTS, the cost of the customer specific facilities is identical, $300.

Second, unlike the distribution facilities on a wireline network, congestion can and does occur on wireless networks. The number of voice channels that can be served by a BTS is constrained by the available radio spectrum. Depending on if omnidirection or sectorized cells are used, the capacity of the BTS can vary, but regardless is small relative to the capacity of wireline facilities.[12] Because of this capacity limitation, if the amount

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areas, wireline networks may have a cost advantage. "Broadband Wireless," Prudential Securities, April 19, 1996, p. 8 (quote), 18.

[12] See, for example, William C.Y. Lee, *Mobile Communications Design Fundamentals*, Second Edition, Wiley Series in Telecommunications; and Gregory P. Pollini, Kathleen S. Meier-Hellstern, and David J. Goodman, "Signaling Traffic Volume

of traffic in a geographical area exceeds the capacity of a BTS, the service area of the tower must be reduced (split). Hence while there are large fixed costs associated with erecting a BTS, the cost must be duplicated where the capacity of a single tower is exceeded. Hence the "distribution" portion of the wireless network is traffic sensitive, as is the, in part, the "feeder" section of the wireless network. As the busy-hour usage increases, the supplier must install additional capacity on its microwave feed from the BTS to the MSC, or rent additional capacity from the wireline network supplier.

III. Results and Discussion.

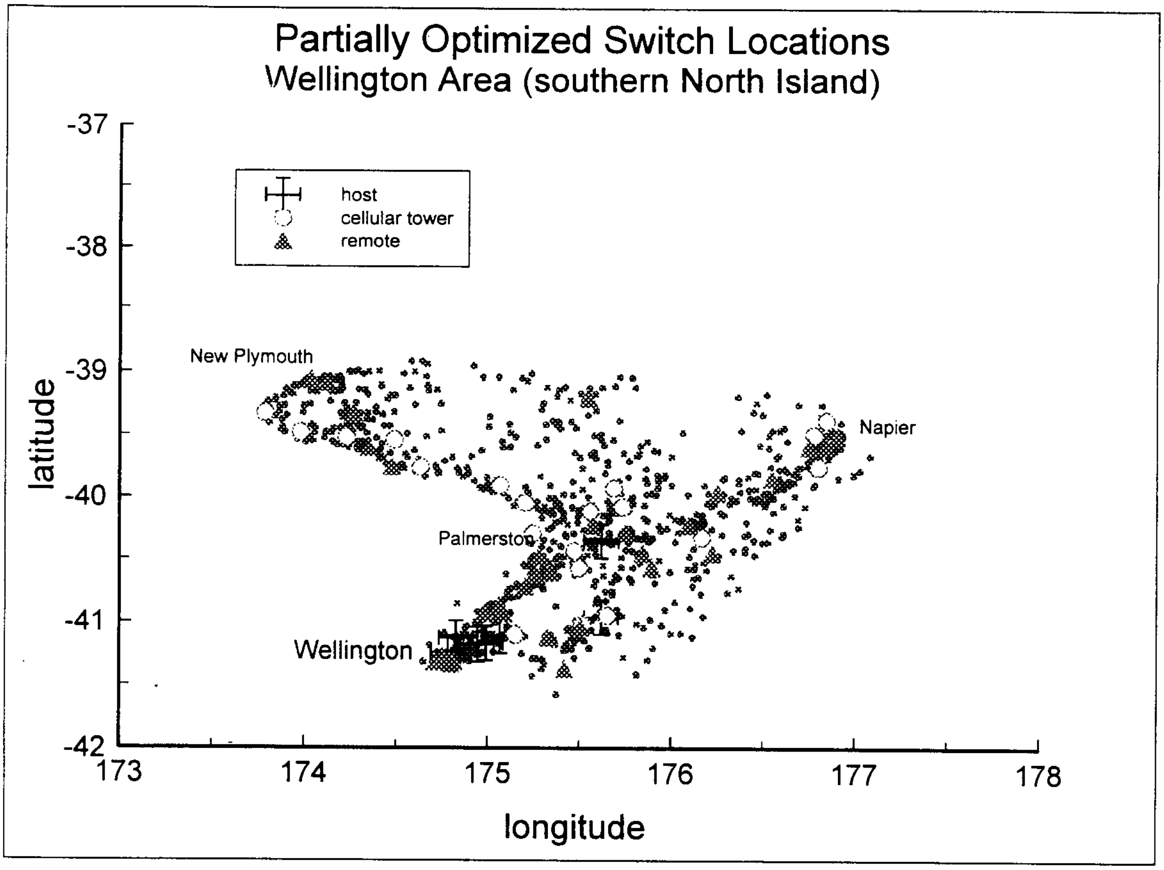
In Table IV we report average cost values for partially optimized networks for each of three regions of interest in New Zealand. There is an important caveat that must be made known up front before we can discuss these numbers. To facilitate the production of this paper, we limited the number of cellular towers that could be installed in each region to 12 in the case of Auckland-Hamilton and 20 in the other cases. In each of the three cases, the optimizing result included this maximum number of cellular towers, suggesting that relaxing the constraint may lead to lower average costs per line.

Table IV: Average Monthly Cost Per Line

Region	Wireline Only (NZ$)	Wireline Plus Cellular (NZ$)
Auckland-Hamilton	54.62	52.54
Wellington	57.04	54.18
South Island	87.48	82.51

Given these caveats, we can still draw some conclusions. First, it would appear that fixed mobile cellular provides a cost-competitive alternative to wireline service in certain rural areas. As the map generated by LECOM below (Figure IV) shows for the Wellington area, this result applies along important rural highways, like the ones between Palmerston and Napier and between Palmerston and New Plymouth.

Generated by Mobile and Personal Communications," *IEEE Communications Magazine*,



These results suggest that fixed mobile cellular meets the "average cost test;" that is, they provide service at a lower average cost than wireline infrastructure in the Wellington area of North Island. We hope to have additional numbers available at the October 30, 1996 conference.

June 1995, pp. 60-65.