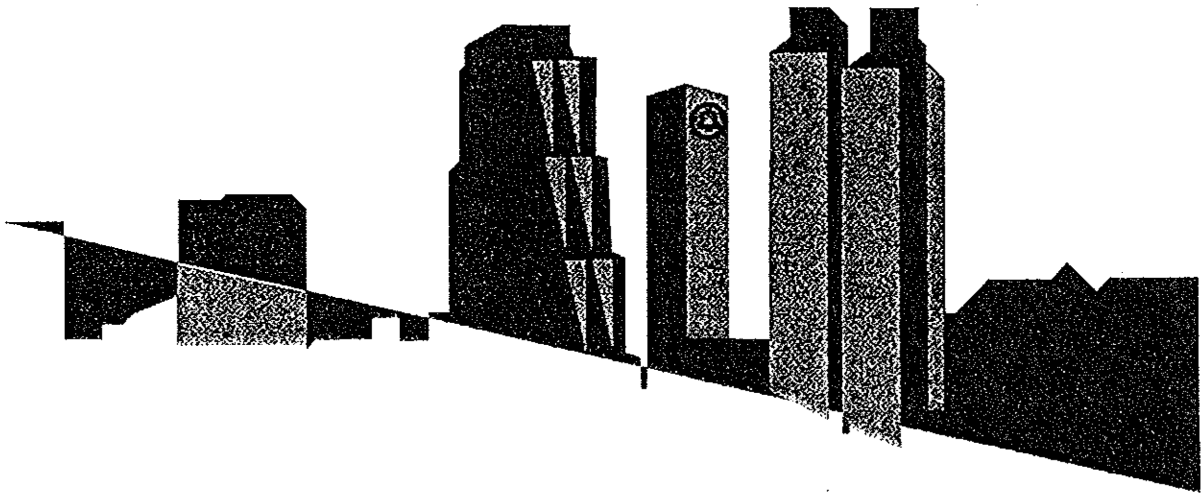

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Cost Comparisons of FTTC and FTTH for Various Demands and Densities

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Abstract

This paper analyzes the installed first costs (IFCs) of representative Fiber-to-the-Home (FTTH) and Fiber-to-the-Curb (FTTC) architectures. The analysis investigates the IFC sensitivity to varying service demands and living-unit (LU) densities for each architecture. We find that in low-penetration or low-density areas, FTTH is less expensive than FTTC, and we quantitatively determine the point of IFC crossover between FTTC and FTTH.

1. Introduction

The existing access networks – the copper loop plant of the public switched telephone network and the hybrid fiber-coax plant of the cable-TV network – provide their services in analog format, and they do so fairly efficiently. However, these access platforms have difficulty supporting broadband bidirectional digital services, unless special modifications are made to the networks.

Interactive broadband digital services are seen as the final goal of access networks, because this service infrastructure can support many services, even those yet to be defined. Such a system can justifiably be called a full-service network (FSN). For this reason, interactive digital service is a key differentiator between the networks of today and the networks of the future. Of the many classes of access networks, fiber-to-the-curb (FTTC) and fiber-to-the-home (FTTH) are the leading condenders for a true, switched, broadband digital FSN. This distinction is a direct consequence of the star network topology used in these systems.

Given this motivation, it is important to understand the choices to be made between FTTC and FTTH. It has been generally concluded that FTTC costs less than FTTH, due to the sharing of central office (CO) equipment, fiber plant, and optical network units (ONUs). However, this general belief does not take into account several important **breakage factors**[1]. Because of this, the utilization of the FTTC shared equipment was over-estimated, and thus FTTC's cost was under-estimated in certain situations. This analysis explicitly includes these factors, and produces new results that demonstrate, for the first time, the situations where FTTH offers the lower installed first cost (IFC).

The remainder of this document is structured as follows. Section 2 further explores the basic trade-offs and breakage mechanisms at play in the comparison of FTTC and FTTH. Section 3 explains the modeling methods used here to compare the two networks. Section 4 presents the results of the IFC modeling, revealing that FTTH is less expensive than FTTC in low-density or low-service penetration areas. Section 5 discusses and summarizes the major results of the report.

[1] Breakage refers to the unavoidable over-provisioning of shared equipment resulting in stranded resources.

2. Key differences between FTTC and FTTH

The fundamental differences between FTTC and FTTH are the degree of equipment sharing in the network and the use of range-limited drop technology. In FTTC, groups of living units (LUs) are homed on a shared ONU placed at the curb location. This ONU contains all the optics, common electronics, and service-defining electronics (i.e., line cards), and is connected to the subscriber residences by twisted-wire-pair (TWP) cable. Low-cost coding techniques are used to carry the broadband (~52 Mb/s) signal a short distance over the TWP cable. Each ONU communicates over a passive optical network (PON) to a shared optical line-termination (OLT) module at the host digital terminal (HDT).

In FTTH, each subscribing LU is provided with its own ONU that communicates with the HDT over a PON. The PON allows the OLT to be shared by several subtending ONUs. Typical optical line rates in FTTH systems are 155~622 Mb/s, and each OLT can support ~16 homes. As a result of this reduced sharing, the ONU cost per potential subscriber for FTTH can be as much as three times higher than that for FTTC.

The misleading aspect of comparisons like this is that the costs are given on a per **potential** subscriber basis. This is only equal to per-subscriber costs when the utilization or fill of the FTTC ONUs or OLTs is 100% with all subtending LUs subscribing to services. In practice, this level of utilization can be difficult to reach, because of three types of breakage: range-induced, grouping-induced, and penetration-induced, which lead to underutilization of the access network or **stranded capacity**. Each of these breakage effects is additive, and tends to accumulate upstream in FTTC networks, reducing not only the utilization of the ONUs but also that of the OLTs and the host digital terminal (HDT).

Range-induced breakage results from the use of TWP to carry the broadband signals from the ONU to the subscriber. The coding techniques used have range limitations due to the limited capabilities of TWP. In our studies, we have assumed this limit is 275 m[2]. This limit implies that the ONU must be placed so that the copper distribution plant plus the drop and inside wiring must be less than 275 m in length to reach any subtending LU. However, when the density of LUs falls below a critical level, there will not be enough LUs within the 275-meter limit to fully utilize a particular size ONU.

Grouping-induced breakage is related to range-induced breakage but is more directly a result of the uneven distribution of houses in real neighborhood layouts. For instance, in a suburban setting, one often finds widely spaced cul-de-sacs, each having a random number of homes. The number of houses found in each cluster need not completely fill an integral number of ONUs. Rational ONU assignment rules or the range limit prevents the transfer of homes across these group boundaries. Hence, there will be grouping-induced breakage of ONUs in FTTC networks.

Penetration-induced breakage is caused by the less-than-complete subscription of the passed homes. With FTTC, ONUs must be placed everywhere in the distribution area,

[2] The range limit depends on many factors, particularly the modulation scheme and bit-rate. The number used here is indicative of current 52 Mb/s CAP based modems. Other systems may have longer range.

because they are part of the shared network infrastructure. This sharing makes the probability of an ONU with no active subscribers (and hence, not being required) very small, even for take rates of only 10%. Further, the randomness of service take dictates that the FTTC ONUs should be sized to accommodate full penetration.

FTTH, in contrast, can be deployed much more selectively. In principle, ONUs can be placed only at subscribers' homes, rather than at every home passed. Since FTTH dedicates an ONU to a single subscriber, its utilization is 100%. The fiber distribution range beyond the first shared element (the splitter) is much longer than the corresponding TWP range in FTTC. As a result, FTTH does not suffer range-induced breakage. Since FTTH has no significant range limitation, we can aggregate the geographically disparate living units into much larger groups at a **shared splitter site**. This makes it technically possible to maintain a high level of utilization on the splitter (PON), OLT, and HDT despite low service penetration.

The overall effect of these three breakages is to reduce the effective utilization of FTTC with respect to FTTH for low LU density and service penetration. Incorporating this factor, the costs per active subscriber for FTTC ONUs and OLTs can equal those of FTTH, and even exceed them in cases where the living-unit density is low or where the penetration of services is low. The following two Sections quantify the combinations of service-related factors (narrowband and broadband subscription levels, and subscriber living-unit density) that trigger the crossover from FTTC to FTTH.

3. Analysis Approach

This Section outlines the procedures followed to design the FTTC and FTTH networks considered here. The FTTC network is based generally on supplier technology available today, and a brief description of the FTTC network is provided in Appendix A. The FTTH network is based on the "FDM PON" system[3] that was described previously in [1]. That paper analyzed several FTTH networks, including a pure TDM PON, an effective FDM PON, a WDM PON, and an active double star network. The FDM PON without broadcast overlay was found to have the lowest cost over the largest range of service penetrations, hence its use in this analysis. We consider these networks to be typical implementations of the two architectures; however, other variants are possible.

3.1 FTTC Modeling Issues

As described above, the breakage effects due to living-unit density and layout, and the FTTC ONU range limitation on the broadband metallic drop are important factors in the efficient deployment of a FTTC system. The intent of this analysis is to quantify the broad outlines of the application areas (subscriber demand and living-unit density) in which each access system holds an IFC advantage.

To capture some of this real-world geographic variability, the approach taken here is based on a residential layout patterned on a real U.S. Midwestern suburb (see Fig. 1). The distribution area (DA) consists of 504 LUs with a density of about 41 LUs/km. To examine the effect of subscriber density variation, the whole layout geometry was scaled. This scaling changes all

[3] The FDM PON is very similar in design to the recently developed ATM PONs, except it uses a special effective FDM coding technique to overlay a secondary STM channel in the PON signal. This makes the provision of narrowband service less costly without requiring any substantial change to the basic ATM PON design.

of the lengths in the distribution area, so that both street lengths of cable and drop runs are similarly scaled. The areas considered here range from a scale factor of 0.22, corresponding to 186 LUs/km or an 11-m frontage per home, to a scale factor of 3.3, corresponding to 12.5 LUs/km or a 162-m frontage consistent with 16,000 square meter (four acre) zoning.

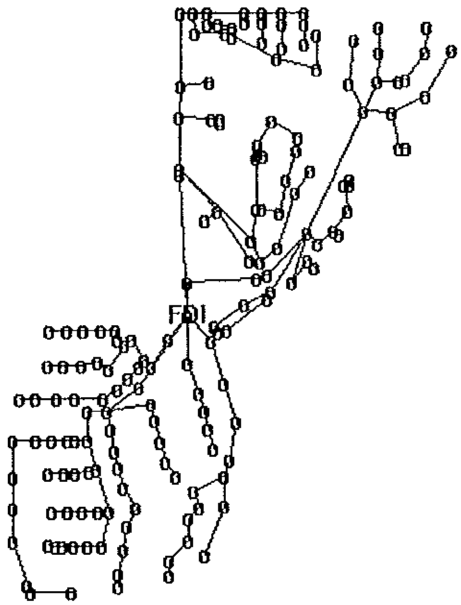

Figure 1. A 504-LU distribution area with the lines indicating cable runs and the nodes representing pole locations for the aerial installation. FTTC ONUs are constrained to be sited at the pole locations (no mid-span ONUs). Homes and drops are not shown. The feeder-distribution interface is indicated as FDI.

Available statistics indicate that approximately 72% of the residential living units in the United States are classified as single-family units [2]. Table 1 provides the single-family statistics for the three different densities included in the current study [3]. Although only 11% of single family units are less than 12.5 LUs/km, a statistic of interest not shown is that ~20% of single-family units are less dense than 18.5 LUs/km (scale factor 2.25) [3].

Table 1. Residential Building Lot Statistics.

Study Scale Factor	Lot Frontage	LU per km	Lot Size A (m^2)	Single-Family LUs with Lot Size ≤ A
0.22	11 m	186	770	27%
1.00	49 m	41	1580	50%
3.30	162 m	12.5	17,400	89%

FTTC ONUs: The FTTC system considered here is assumed to provide three different ONU "sizes" with differing narrowband and broadband capacities on their backplanes (narrowband: 48 DS0s, 36 DS0s, and 24 DS0s; broadband: 16, 12, and 8 drops). We also assume that the system is to be deployed with an ultimate capability of 3 DS0s per LU which implies that these units are capable of serving a maximum of 16, 12, and 8 LUs, respectively. The 16-LU, 12-LU, and 8-LU ONUs are fed from OLTs with a capacity of 96 DS0s/32 LUs.

A Bellcore-developed software tool [4] was used to automate the task of selecting ONU sizes and siting ONUs in the scaled distribution areas. The tool minimizes the total cost of all the ONUs installed in the area consistent with the constraint that all the subtending LUs connected to a given ONU are within the maximum range limit. In practice, the result is that the routine maximizes the number of subtending LUs per ONU (to limit cost) and favors the use of larger ONUs since these are more cost-effective when fully utilized.

Figure 2 illustrates the relative counts of the three ONU sizes utilized at the different levels of LU density. At densities of about 41 LUs/km or higher, the homes are close enough together that nearly all homes can be served from 16-LU ONUs. A few of the smaller size units are needed to cope with small clusters of LUs. However, as the density drops below about 41 LUs/km, the picture changes rapidly as increasing numbers of the smaller size ONUs are called for. If the FTTC broadband range were smaller (or larger) than 275 m, the onset of the transition from larger to small ONUs would occur at higher (or lower) density.

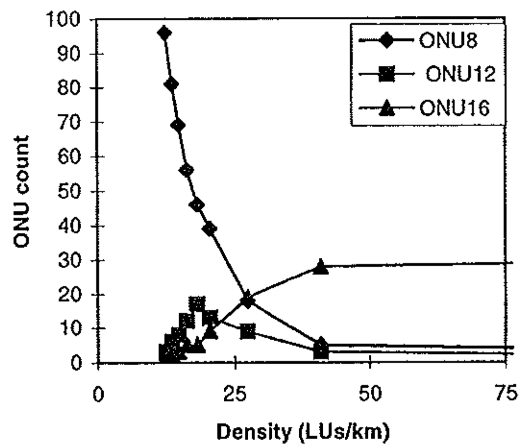

Figure 2. The number of the three ONU sizes utilized versus the density of the scaled distribution area.

The move to smaller size ONUs depicted in Fig. 2 is significant for another reason: for some FTTC systems, the smallest size ONU commons corresponds to the 16-LU ONU considered here. For such a system, the lower density areas would be very costly to serve because the number of these more expensive ONUs would rise rather than fall as density decreased.

FTTC Outside Plant: Each FTTC ONU requires two fibers in the distribution facility (here assumed aerial). As the total count of ONUs increases with decreasing density (see Fig. 2), the fiber plant grows more costly because in addition to needing greater lengths of cable, the fiber count in the cables grows. More active fibers implies more optical splitters and (see below) more feeder fibers and more OLTs. The feeder facility length is fixed at 3-km for both the FTTC and FTTH cases.

A countervailing factor arises with the cost of the copper distribution plant which actually decreases as the plant is scaled up in size. The reason for this decrease is rooted in the fact that for this model, the drop lengths also scale up with the rest of the plant. The result is that the ONUs must move even closer to the served homes because more of the 275-m length is taken up by drop plant. Because aerial installation is assumed, drops are installed on an as-needed basis (similarly for the FTTH case).

FTTC HDT and OLTs: With some current FTTC systems, once a single subscriber is active at a FTTC ONU, that ONU commands a fixed share of the PON capacity as large as if it were fully occupied[4]. As the density decreases, breakage at the ONUs is translated to an increased number of the relatively costly OLTs required at the HDT. In addition, since the HDT commons are capable of supporting only a limited number of OLTs, a greater fraction of the cost of the HDT commons must be allocated to the 504 LUs. The efficiency with which the HDT commons can be utilized decreases with decreases in the LU density as shown in Fig. 3.

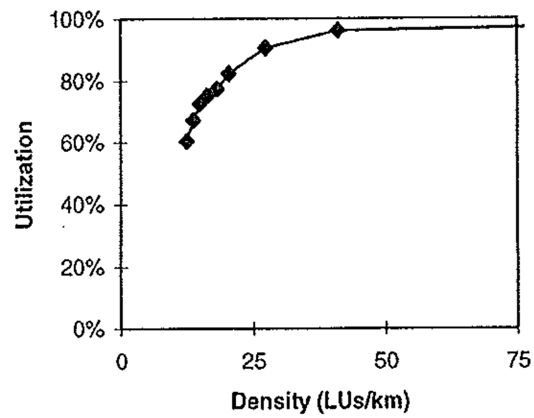

Figure 3. The efficiency of utilization of HDT common equipment versus subscriber density.

At any given density (or scale factor), the automated package for siting ONUs defines the size and location of each ONU, and the number of subtending households attached to each ONU. From this information, one can determine the number of OLTs which must be provided, and consequently, the fraction of the HDT commons which must be allocated to this DA.

3.2 FTTH Modeling Issues

The effects of scaling on the cost of the FTTH system are much easier to describe. Within the range of the distribution facilities considered here, there are no range-sensitive limitations akin to the broadband metallic drop length. As a result, the costs of the fiber cable facilities and fiber-drop facilities increase linearly with the increase in scale of the distribution area. There are no changes in fiber or splitter counts. The number of ONUs is set by the subscription levels to narrowband and broadband services. ONUs are assumed to be locally powered at the home.

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4 Strictly speaking, this comment applies to the narrowband capacity. Since this system tends to be constrained more by the narrowband capacity than by the broadband, the effect is largely the same. Future systems may lift this constraint, but are beyond the scope of this study.

FTTH systems bring a new option to the table which is not present for FTTC systems. One of the key aspects of FTTH systems is the ability to defer installation of the costly FTTH ONU until the customer subscribes. We assume here that a fully capable fiber feeder and distribution plant is installed on day one. However, the placement of the fiber drop and ONU is assumed to occur on an as-needed basis. Doing so introduces an attractive option with regard to how the active ONUs are connected back to the CO.

This option, which we term the **fully utilized FTTH** scenario, entails connecting only the active distribution fibers to splitter ports. The passive splitters are concentrated at four locations in the DA to facilitate this. By only connecting active distribution fibers (i.e., fibers serving subscribing homes) to the splitters, one can keep a high level of utilization of the PON and its associated OLT and HDT common equipment. In the following analysis, however, only the fully utilized case will be considered.

3.3 Service Penetration Mix

Most of the above discussion of ONU efficiency, HDT utilization, and how they are changed with the density of the DA is independent of the service penetration. However, the cost modeling of both the FTTH and FTTC systems is not complete without considering the service-dependent components at the ONU and HDT. We assume that the penetration of narrowband services is equivalent to the probability p_{NB} of any given LU subscribing to narrowband services, and likewise, that the penetration of broadband services is equivalent to the probability p_{BB} of any given LU subscribing to broadband services. For simplicity, we assume that the two services are statistically independent. This means, for example, that the probability that a given LU takes any service, p_{SUB}, is given by $p_{SUB} = [1-(1-p_{NB})*(1-p_{BB})]$.

For the FTTH case, the fraction of LU equipped with an ONU commons is given by p_{SUB}, the fraction with a two-line narrowband plug-in by p_{NB}, and the fraction with a broadband plug-in by p_{BB}. The situation at FTTC ONUs is more complicated. Here, the ONU is assumed to accommodate two types of quad card plug-ins: one for narrowband and the other for broadband service. The number of narrowband and broadband quad plug-ins is given by considering the statistical fluctuations in the number of homes that might subscribe out of the cluster of homes at any given ONU. This calculation involves knowing how many homes are actually assigned to the ONU, and results is an expected number of quad cards of each type.

For both the FTTH and FTTC cases, the required number of DS1 plug-ins at the central office is determined by the number of DS0s serviced by the HDT and the concentration ratio. Similarly, the number of OC-3c plug-ins at the central office can be calculated from the number of broadband broadcast channels and the traffic demands of the interactive broadband services (video on demand, Internet access).

4. IFC Results

The comparison of the IFC results is complicated by the many-dimensional nature of the analysis: the analysis provides cost as a function of the narrowband service penetration, the broadband service penetration, and the subscriber density. One way to visualize the combinations of parameters which favor FTTC vis-à-vis FTTH is shown in Fig. 4. These charts delineate the combinations of broadband and narrowband take rate which favor the

FTTH and FTTC systems. The left chart is computed for subscriber density is 12.5 LUs/km, and the right chart is for a density of 41 LUs/km. What we see is that at both densities, FTTC offers lower IFCs when the combined service take rates are high. The region in which this is true increases with increasing subscriber density. Nevertheless, in a semi-rural region, FTTH can be cost competitive with FTTC with a narrowband take of 50% (or less) and a broadband take of 30% (or less). Not unrealistically low service penetrations in a multi-provider marketplace.

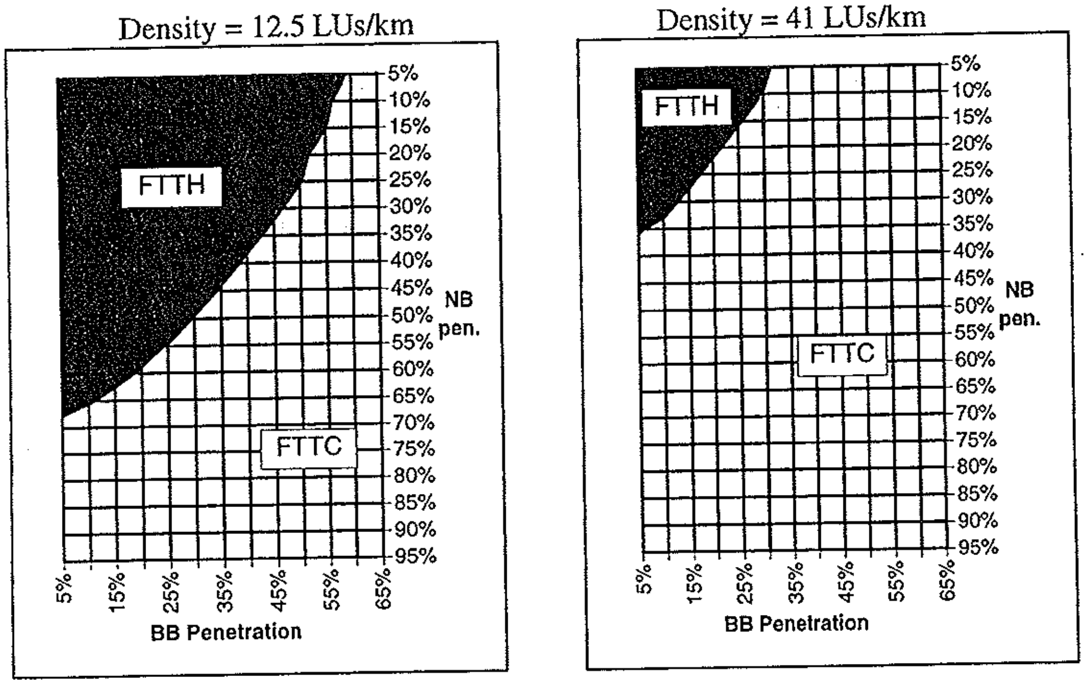

Figure 4. The two regions in each chart above indicate the combinations of broadband and narrowband penetration for which the FTTH and FTTC systems are the lower cost alternative for the indicated values of density.

The two charts in Fig. 4 clearly indicate the regions in which each system offers the lower IFC, but they provide no information on the sensitivity of the cost to variations in the service penetration. To quantify the cost sensitivity for any system, we can define the difference between the cost of that system and the cost of the least-costly system, and express this difference as a percentage of the cost of the least-cost system (all costs are for the same NB and BB penetration). We refer to this measure as the "%Δ IFC from the minimum." An advantage of this measure is that the results are independent of whether we consider IFC on a per-home-passed basis, on a per-subscriber basis, or on a per-service-appearance basis. A disadvantage of this measure is that the %Δ IFC measure will somewhat overstate the percentage cost difference because the cost of settop boxes was not included[5]. Figure 5 shows the %Δ IFC for FTTH (left chart) and FTTC (right chart) systems at a density of 12.5 LUs/km. Comparing the two charts of Fig. 5, we see that at a density of 12.5 LUs/km, the FTTH system is always within 20% of the minimum cost and within 10% of the minimum over most of the

[5] These cost components were omitted because they are identical for FTTH and FTTC and, as such, do not differentiate the two systems.

plot region. The FTTC system is within 10% of the minimum over a similarly large region. At very low penetrations, the FTTC system can cost over 50% more than the FTTH system. There is substantial overlap of the region in which the two systems' IFCs are within 10%.

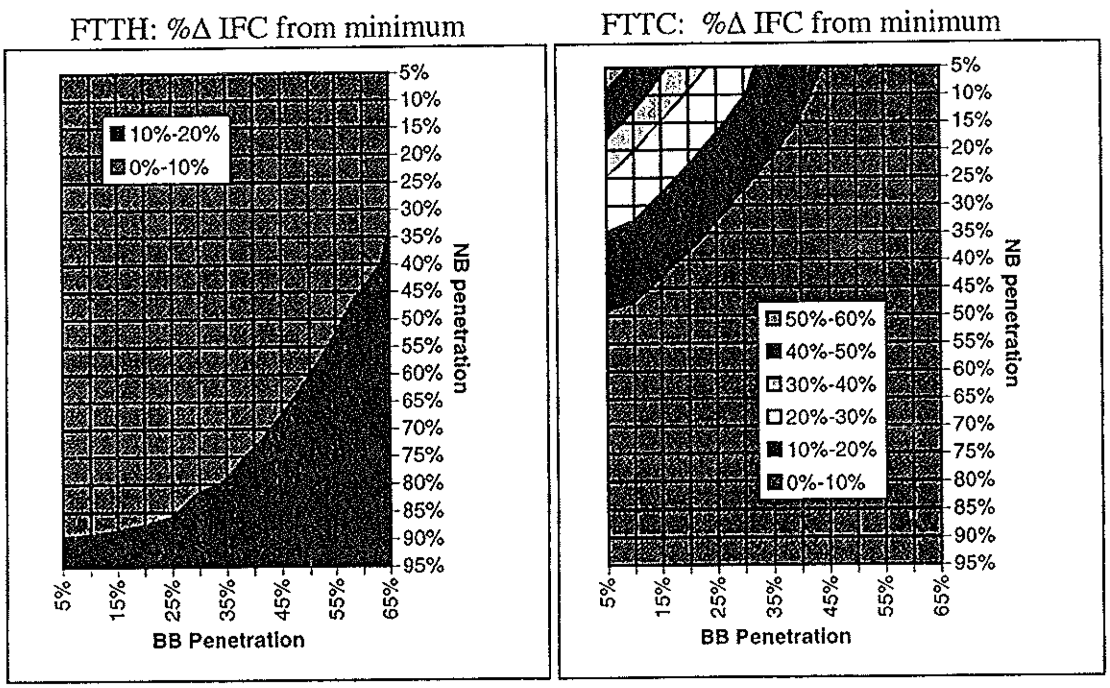

Figure 5. For the FTTH system (left) and the FTTC system (right), the contours indicate the percentage by which the IFC exceeds the minimum cost relative to the minimum cost at a density of 12.5 LUs/km.

Another way to visualize the comparison between FTTH and FTTC is to determine the combinations of density and service penetration that favor one system over the other. Figure 6 shows which system has the lower IFC for various combinations of LU density and total penetration. The total penetration is computed using the simplification that the penetration of both NB and BB services are the same. This chart demonstrates that once the total service penetration falls below ~35%, FTTH becomes less costly than FTTC regardless of the density. Similarly, once the density falls below ~10 LUs/km, FTTH is less costly than FTTC regardless of service penetration. Stated in this way, these results provide a simple guide for the comparison of FTTC and FTTH networks.

It is interesting to compare FTTH and FTTC in terms of incremental service costs. The graphs in Fig. 7 show both the cumulative IFC per homes passed and the incremental IFC per service appearance as the total service penetration increases for the two networks in the 41 LUs/km density case. Thus, IFC curves in Fig. 7 present a diagonal cross-section of the same data as in the 41 LUs/km case in Fig. 4. The cumulative IFC curves show that the zero-penetration 'fixed' cost is lower for FTTH. As the penetration increases, the FTTH IFC increases faster than the FTTC, crossing over at 38% total penetration.

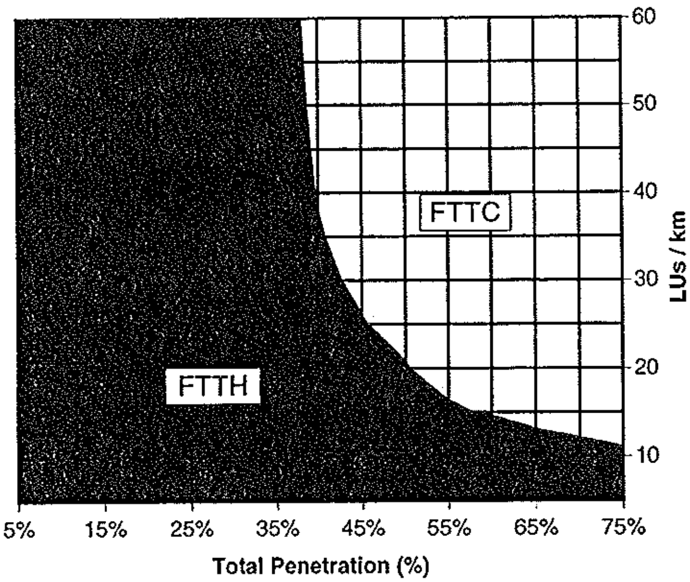

Figure 6. The two regions in each chart above indicate the combinations of total penetration and density for which the FTTH and FTTC systems are the lower cost alternative.

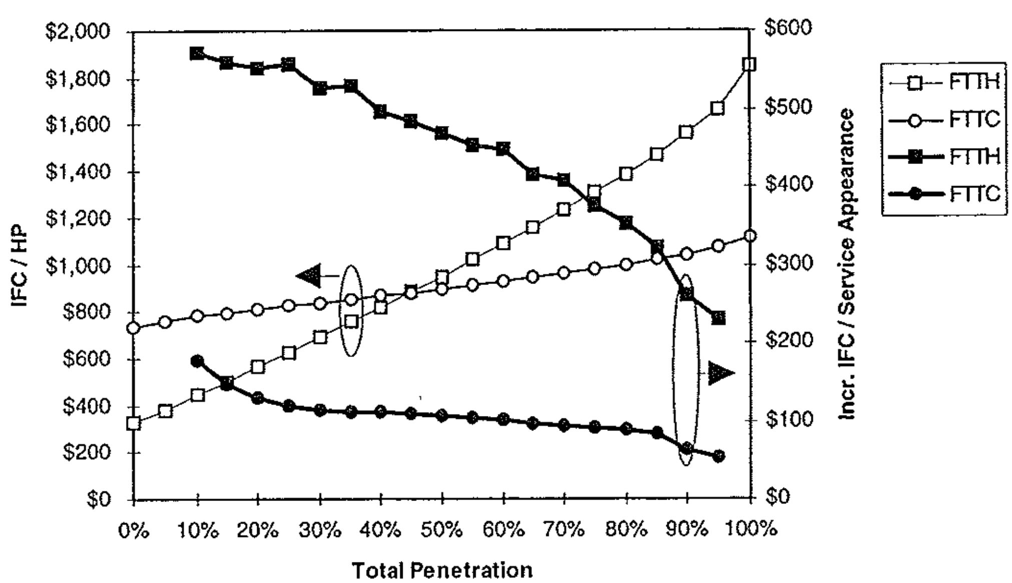

Figure 7. The cumulative IFC/HP and the incremental IFC/SA for the FTTH and FTTC networks at 41 LUs/km.

The incremental IFC per service appearance (SA) curves show the costs incurred by the two systems to add additional service appearances (on an averaged basis). This result shows that FTTH has incremental costs that are five times larger than that of FTTC. This underscores the **fundamental difference between FTTC and FTTH**: FTTC requires major investments in fixed plant and equipment, whereas FTTH shifts the investment to service dependent equipment. This difference may play an important role in system selection, particularly in light of the recent **unbundling** decisions that point towards incremental costs as the basis for price regulation. These would tend to favor systems that require less fixed cost and more incremental cost.

The major cost driver in FTTH networks is the dedicated ONU. It must be pointed out that the costs used in this study are based on 100,000 unit volumes in a 1998 time frame, and no learning curve cost reductions have been applied. With a deployment of one million subscribers would drive the ONU related costs of FTTH down by about 30%. This assumes a learning curve factor of 90% per doubling, and 3.3 doublings. Taking this into account for 41 LUs/km density, FTTH has lower total IFC than FTTC at 50% total penetration or less.

5. Summary and Conclusions

This paper has compared the delivery of a full-service network capability via FTTC and FTTH on an IFC basis. The key element in this study is the inclusion of underutilization effects. We find that both range limitations and low penetration severely impact the IFC of FTTC relative to FTTH. These effects are large enough to overcome the intrinsic cost savings of FTTC, and make FTTH the lower-cost alternative in certain penetration and LU-density settings.

An analytical model of the networks was constructed to quantify the effects of real-world neighborhood layouts, range induced breakage, and penetration effects. Detailed comparisons of IFCs were made for many common penetration and density settings, and for the systems analysed here, these results point towards the following two observations:

- When the LU density is less than ~10 LUs/km, FTTH is less expensive than FTTC regardless of total service penetration (narrowband + broadband).
- When the total service penetration (narrowband + broadband) is less than ~35%, FTTH is less expensive than FTTC regardless of LU density.

Other key conclusions that emerge from this study are:

- In the next few years, volume-based cost reductions in ONU optoelectronics should differentially advantage FTTH systems.
- FTTC costs depend critically on drop-length limitations, which governs the maximum ONU sharing that is possible for any given size of ONU.

6. References

[1] F. J. Effenberger, K. W. Lu, "An Overview of FTTH Networks – Past History, Current Status, and Future Designs," Broadband Access Systems, Proc. SPIE 2917, pp. 293-304 1996.

[2] U. S. Bureau of the Census, Statistical Abstract of the United States: 1995 (115th edition) Table 1230, p. 737, Washington, DC, 1995.

[3] U. S. Bureau of the Census, Statistical Abstract of the United States: 1991 (111th edition) Table 1282, p. 726, Washington, DC, 1991.

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Appendix A – Description of FTTC Architecture

The FTTC network used in this analysis consists of the HDT connected to subtending curb-based ONUs over a splitter-based two-fiber PON. In this system, TDM is used in the downstream direction to combine NB and BB services over the optical links. TDMA is used in the upstream direction for communication from ONUs to the HDT. The OLTs at the HDT support optical line rates of ~1 Gb/s and ~52 Mb/s in the downstream and upstream directions, respectively.

The HDT terminates the high-speed interfaces from the NB and BB backbone networks and provides the interface to operations systems. The ONUs terminate the TWP facilities that carry NB and BB services to customer residences. We assume three sizes of ONUs are available that use three different split ratios to provide various numbers of service interfaces as summarized in Table A.1.

Table A.1. Summary of FTTC ONU Types.

ONU Type	LU Served	ONUs/PON	Split Ratio	NB Interfaces	BB Interfaces
ONU-8	8	4	1:4	24	8
ONU-12	12	3	1:3	32	12
ONU-16	16	2	1:2	48	16

Figure A.1 provides a block diagram showing the relationship between the HDT and ONUs as well as the HDT interfaces to NB and BB backbone networks. The key feature of the FTTC network is the sharing that is achieved by serving multiple LUs from each ONU. This, in combination with the optical splitting, results in the potential to serve up to 32 LUs, providing the capacity for three DS0s per LU, from each OLT in the HDT at full utilization.

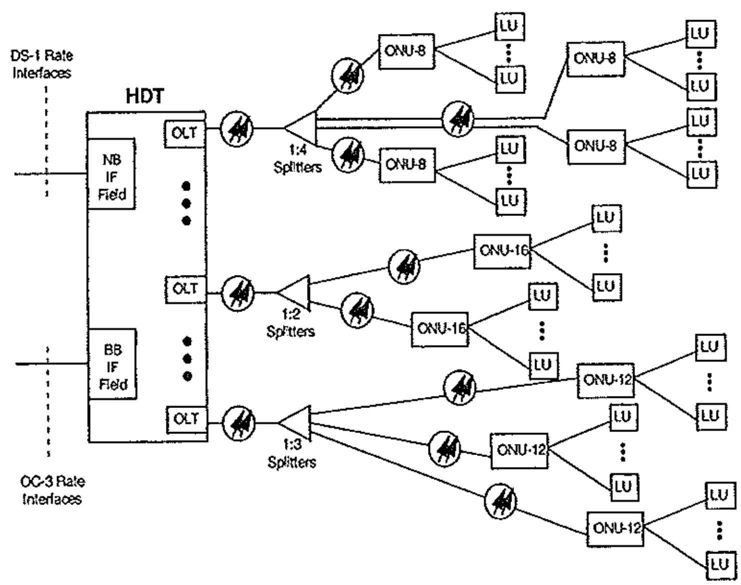

Figure A.1. A PON-based FTTC system using three different ONU sizes.

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Doc Name – 1 **Bellcore**

Outline

- Mechanisms which differentiate FTTC and FTTH deployments
- Approach to modeling
- System models
- Economic comparisons

Doc Name – 2 **Bellcore**

Key Differences Between FTTC and FTTH

- Sharing of ONU common optoelectronics
  - when fully utilized, FTTC ONU cost per subscriber << FTTH ONU
  - in absolute terms, FTTC ONU cost > FTTH ONU
  - original narrowband systems: 4 to 8 LUs/ONU
    current broadband systems: 8 to 16 or more LUs/ONU
  - FTTC ONU is part of infrastructure

- Range-limited metallic drop beyond the FTTC ONU
  - switched digital video systems transport ~50 Mb/s digital signal ~300 m (1000') over twisted-pair facilities

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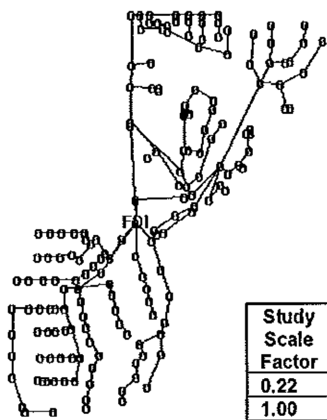
Deployment -related issues for FTTC

- **Stranded FTTC ONU capacity due to three types of breakage penalty:**
  - **Range-induced (assuming 900 ft max. over twisted pair distribution and drop)**
  - **Grouping-induced (nonuniform distribution of homes along streets)**
  - **Penetration-induced (FTTC ONU sized to accommodate full penetration)**

Doc Name – 4 **Bellcore**

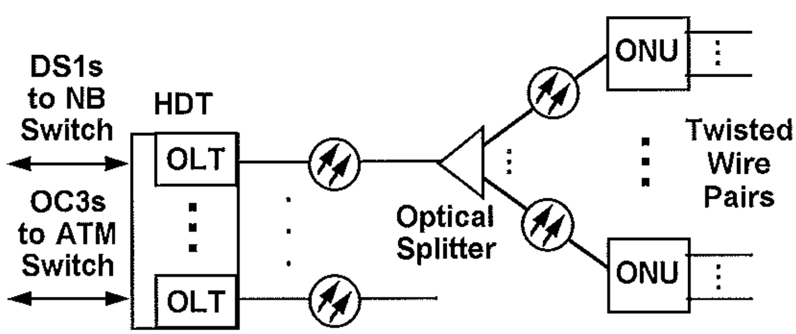
Model Distribution Area



- 504-home suburban distribution area
- 1280m x 1630m (4200 ft. x 5350 ft.)
- ~ 40 LUs/km (66 LUs/mile)
- Scale entire layout up or down to reflect density changes

Study Scale Factor	Lot Frontage	LU per km	Single-Family LUs with Lot Size ≤ A
0.22	11 m	186.0	27%
1.00	49 m	41.0	50%
3.30	162 m	12.5	89%

FTTC Architecture

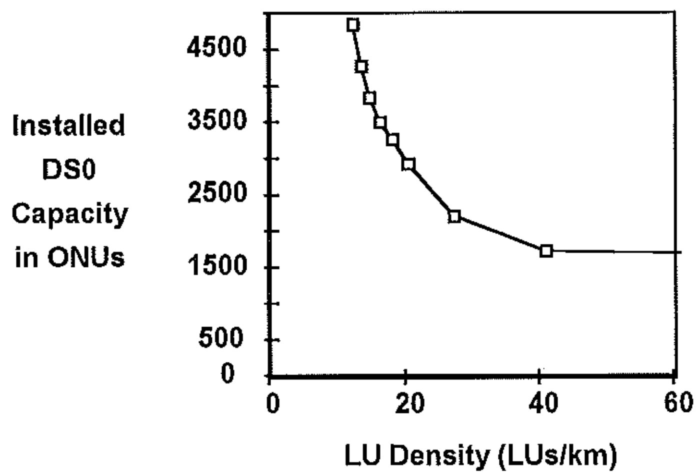


OLT and PON support 32 LUs

ONUs characterized by:
size (16, 12, 8 LUs/ONU)
reach (300 m, 900')
cost

Impact of Decreasing Density on FTTC

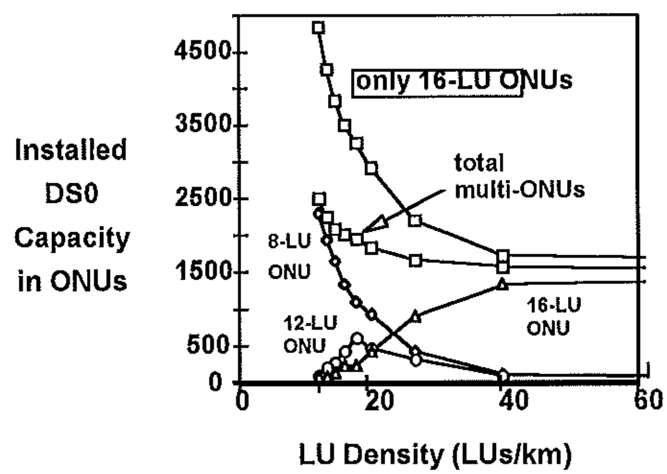
Only 16-LU ONUs



Doc Name – 7 **Bellcore**

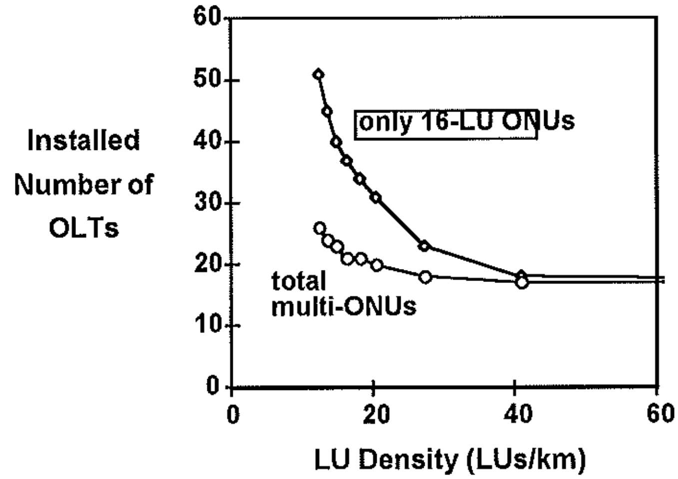
Impact of Decreasing Density on FTTC

Multiple FTTC ONU Sizes



Doc Name – 8 **Bellcore**

HDT OLTs
"Inefficiency propagates upstream"



Doc Name – 9 **Bellcore**

Question and Approach

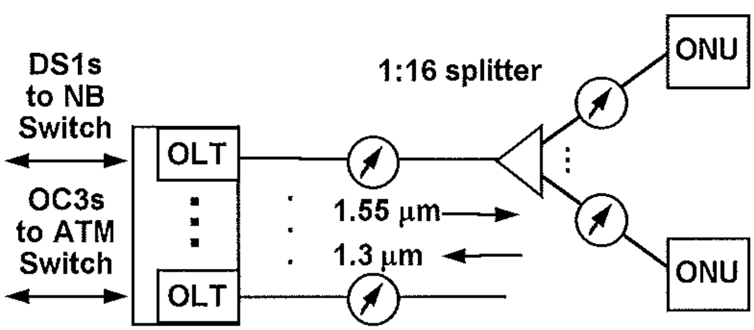
- What combinations of narrowband and broadband service take and subscriber density result in sufficiently low utilization of FTTC to offset its intrinsic IFC advantage?
- Full-blown economic model, pricing levels assumed volumes of 100,000
- Fully-install all aerial fiber and metallic infrastructure sufficient for 100% subscription

Doc Name – 10 **Bellcore**

Cost Scaling with Density

- FTTC costs tend to scale faster than linearly with scale factor
  - more ONUs implies more fiber count in addition to greater fiber cable length
  - more ONUs implies more splitters, more OLTs and greater allocation of HDT commons
  - total metallic distribution costs increase but mostly in drop, copper distribution cable costs actually decline
  - powering costs
- Comparable FTTH costs tend to scale linearly or sub-linearly with scale factor

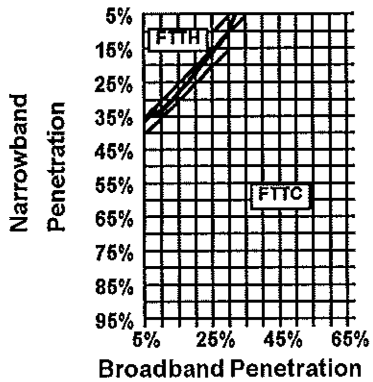
FTTH Architecture



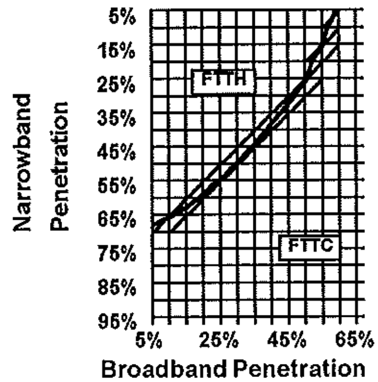
OLT and PON
support 16 LUs

IFC Comparison: Impact of Service Mix

Density = 41 LUs/km



Density = 12.5 LUs/km

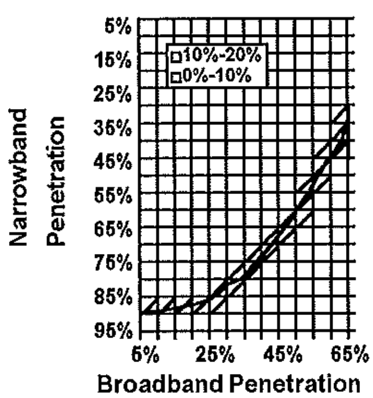


Doc Name - 13 **Bellcore**

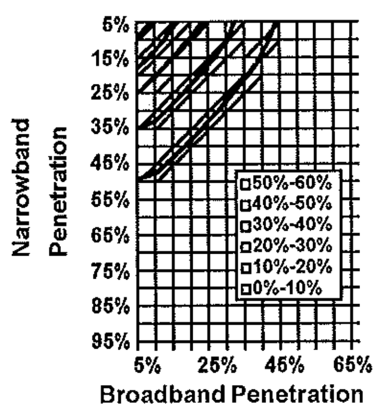
IFC Comparison: % Δ from minimum

Density = 12.5 LUs/km

FTTH

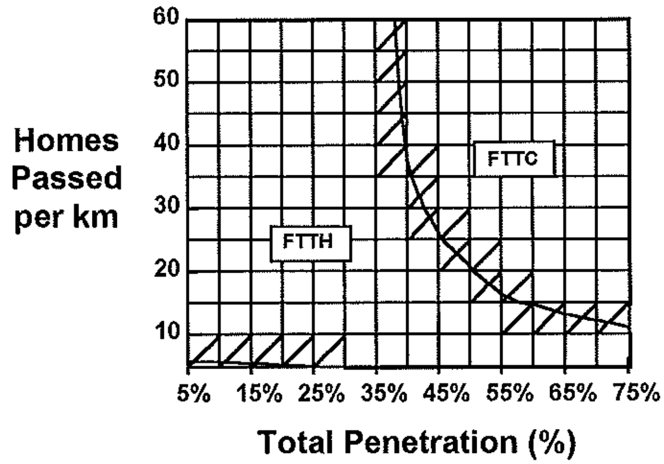


FTTC



Doc Name - 14 **Bellcore**

Impact of Subscriber Density and Take



Doc Name – 16 **Bellcore**

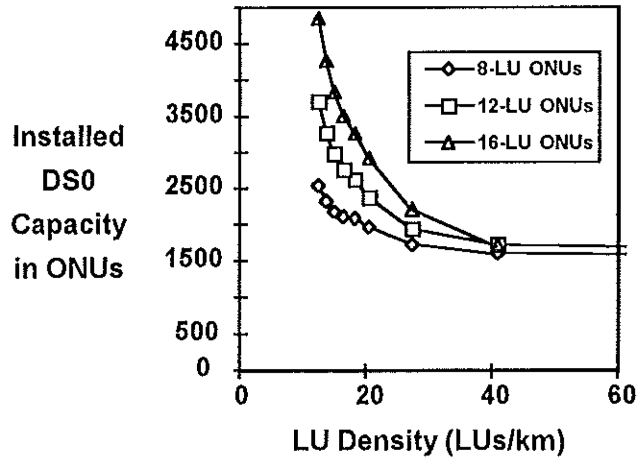
Summary and Conclusions

- Range-limited drops and real-world residential layouts can limit the efficient deployment of FTTC in low-density areas
- Combinations of low service penetration and low subscriber density can offset the sharing advantage of FTTC at present costs
- Volume-based optoelectronic cost decreases should preferentially advantage FTTH
- Projected operations cost differences are to the advantage of FTTH
- FTTC systems can benefit from smaller ONU sizes

Doc Name – 16 **Bellcore**

Impact of ONU Size

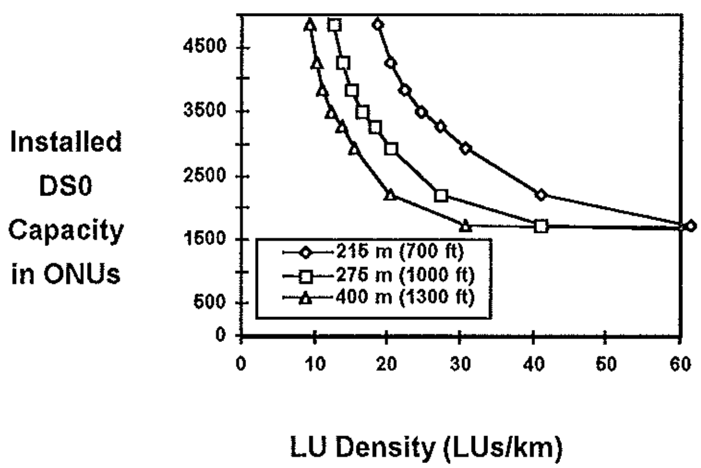
1000 ft. range (275 m)



Doc Name - 17 **Bellcore**

Impact of Drop Range from FTTC ONU

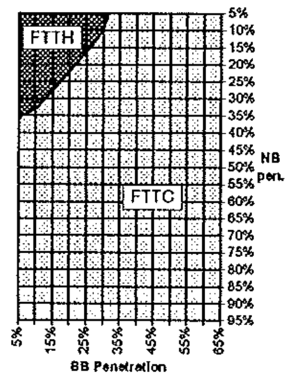
16-LU ONUs



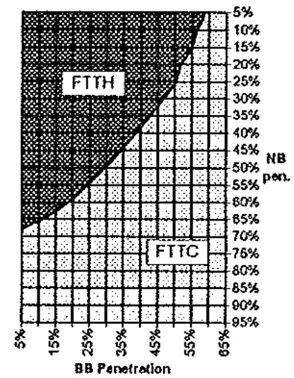
Doc Name - 18 **Bellcore**

Impact of Service Mix

Density = 41 LUs/km



Density = 12.5 LUs/km

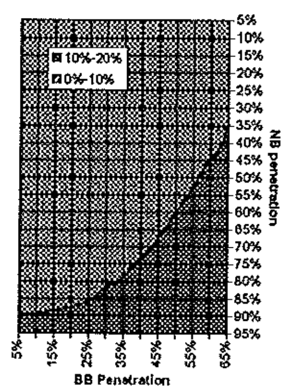


 Bellcore

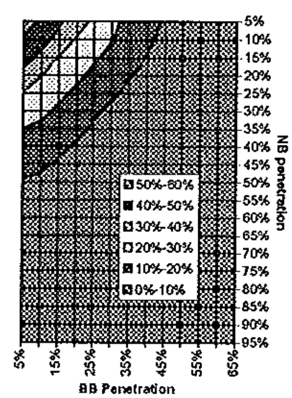
IFC Comparison: % Δ from minimum

Density = 12.5 LUs/km

FTTH



FTTC



 Bellcore