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Estimation of Total Bandwidth and Number of Fiber Per Trench for FTTx Deployments

By Smart Cities Committee

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Contributors

Arvind Mishra, Sterlite Technologies Ltd.arvind.mishra@sterlite.com
Stephen G Foster, (Chair, SCC) Emtelle Asia Pacific (M) Sdn Bhd. ... stevef@emtelle.com.my
William Hamilton, (Vice-Chair, SCC) Ultrafa ... st Fibre Limited ... william.hamilton@ultrafast.co.nz
Abhinandan Sharma, (CommScope) ... Abhinandan.sharma@commscope.com
Adnan Siddiqui, Cyber Internet Services Pvt. Ltd. ... adnan.siddiqui@cyber.net.pk
Allen Wong, PCCW Limited (HKT) ... allen.yc.wong@pccw.com
Craig Price, PCCW Limited (HKT) ... craig.price@pccw.com
Fouad (Frank) Jaffer, Senko Advanced Components (Group) ... frank.jaffer@senko.com
Girish Gupta, Sterlite Technologies Ltd. ... girish.gupta@sterlite.com
Guven Togan, PCOM Technologies Sdn Bhd ... guven.togan@pcom.cc
Katherine Kwan, PCCW Limited (HKT) ... Katherine.sy.kwan@pccw.com
Kwee Chew Lee, Milliken Asia Pte Ltd ... KC.Lee@Milliken.com
Leckraj Raja Rai Basgeet, Mauritius Telecom Ltd. ... rai.basgeet@telecom.mu
Lei QIAN, Milliken Asia Pte ltd ... Lei.qian@milliken.com
Mark Humphreys, GE Grid Solutions ... mark.humphreys@ge.com
Michael van Moppes, Plumettaz Singapore Pte. Ltd. ... michael.vanmoppes@plumettaz.com
Mitra Anirudhya, Corning ... MitraA2@corning.com
Pratik Shah, DSM Functional Materials ... Pratik.shah@dsm.com
Preetam Kumar Ramsoondur, Mauritius Telecom Ltd. ... bobby.ramsoondur@telecom.mu
Sasongko Bayuseto, PT Buana Selaras Globalindo ... bayu@buanasg.co.id
Setyo Budi Agung, Telkom IDEC Innovation & Design Center ... setyo_ba@telkom.co.id
Venkatesan Babu, DSM Functional Materials ... venkatesan.babu@dsm.com
Victor Ko, PCCW Limited (HKT) ... Victor.tc.ko@pccw.com
Vipin Jain, Viavi Solutions Inc. ... Vipin.Jain@viavisolutions.com
Wataru Katsurashima, Sumitomo Electric Industries, Ltd. ... katsurashima-wataru@sei.co.jp
Zain Mulyana, PT. Buana Selaras Globalindo ... zain@buanasg.co.id

In collaboration with

Dr. Abhishek Dixit

Assistant Professor, Dept. of Electrical Engineering,
Indian Institute of Technology Delhi

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Abstract

In this white paper, we present a model that estimates the bandwidth and the number of fibers required to support applications at a high data rate in passive optical network (PON).

The average bandwidth required per user depends on guaranteed grade of service (for which assured bandwidth is made available), application, and the selection of technology (point-to-point or point-to-multipoint). In addition, the fiber count is also clearly a function of user density. Therefore, it is important to consider appropriate fiber count at a green field deployment stage, taking into account the expected growth in the number of applications, bandwidths required in the future applications and the number of users.

I. Introduction

Advances in network devices and the proliferation of bandwidth-hungry applications have created the need for high-speed access networks. Fiber to the x[1] (FTTx) networks has emerged as an acceptable future-proof solution for access networks due to their ultra-high bandwidth capacity, enhanced security, high reliability and low power consumption[1]-[2].

An important factor that needs to be considered in FTTx deployment is the length of the fiber that needs to be deployed in a trench depending upon the user density and other demographics parameters. Communications services providers should also be able to predict the future bandwidth requirements in that area. The fiber deployment should not only serve the surging data traffic but also provide sufficient spare capacity for protection, upgrade and operations & maintenance (OAM).

In this paper, a model for bandwidth estimation and fiber count per trench for upcoming years is presented considering various demographic factors such as population density, number of active users and data rate requirements supporting good grade of service. This study can be considered as guidelines for green field FTTx deployment in rural, urban, and dense urban scenarios.

II. Bandwidth estimation

The bandwidth requirement depends upon various factors: number of subscribers per street (N_T), bandwidth requirements per home (B_u),the probability of a user to be ON(P_{ON}), and the required grade of service.

Let the mean number of active users be N, then assuming Poisson distributed traffic, the probability of r users to be active at a particular time is given as:

$$P(number\ of\ active\ users = r) = \frac{N^r \exp(-N)}{r!} \tag{1}$$

[1] Where x can be H denoting home, B denoting building, A denoting Antenna and C denoting curb

The mean number of users N can be calculated as

$$N = P_{ON} \times N_T \tag{2}$$

If PT is the blocking threshold limit (or similar to a grade of service of a telephone network), then Eq (3) must satisfy.

$$P_T \geq \sum_{r=1}^{z} \frac{(P_{ON} \times N_T)^r \exp(-(P_{ON} \times N_T))}{r!} \tag{3}$$

where z is the minimum number of active users between 1 and NT for which PT remains below blocking probability. The required line rate for the system can be calculated as

$$Line\ Rate = z \times B_u \tag{4}$$

The variation of above mentioned factors are discussed below:

1) Number of users using Internet

The number of subscribers has been growing exponentially with an addition of 10% users every year. For example, at this moment there are 408 million Internet users in India and will reach to 832 million users by 2027 [3].

2) Bandwidth requirement per house

The bandwidth requirement for a home user is described in reference [4]. It can be as high as 1 Gb/s today and further increased to 10Gb/s in future (say 10 years from now)in view of the growth of next generation applications like 3D multi-view panorama TV, smart security with 8K UHD streaming, cloud storage, and wearable technologies. In order to estimate bandwidth growth, we have used Neilson's law which is commonly used to predict the exponential growth of data rate requirement with time. Therefore, the Increase in data rate or bandwidth requirement per home user can be assumed as:

$$B_2 = B_1 \times 1.5^{y_2 - y_1} \tag{5}$$

where B_2 is the peak access data rate in the year Y_2 and B_1 is the peak access data rate in the year.

3) User activity:

According to the Ofcom report 2016[5], the amount of time an adult spends on the Internet is increasing linearly with additional 15 minutes every year. An adult spent 21.6 hours/week (12.8% of a day) on Internet in the year 2015; it is expected to reach 31.8 hours/week (18.9% of a day) by the year 2025as shown in Figure 1).

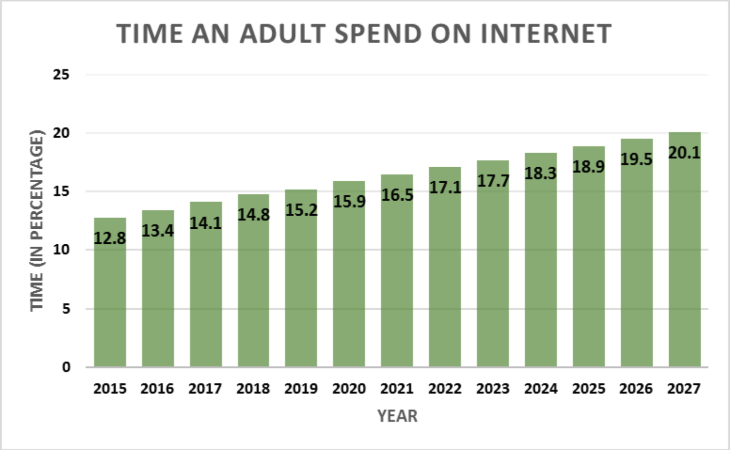

Figure 1: Percentage of time an adult spent on Internet a day with Year (based on Ofcom report [5])

4) User density

For the analysis, we considered three user density scenarios: dense urban, urban, and rural. The dimension of the homes and the homes per street are considered as provided in [6].The number of subscribed users per street, current Internet penetration, and the year in which the Internet penetration is expected to increase to 100% in all three scenarios are given in Table 1

Table 1: Number of subscribed houses in the street (based on the above mentioned assumptions)

	Dense urban	Urban	Rural
Number of subscribed houses in the street	22	11	7
Internet penetration in 2016	39%	27%	13%
Year of 100% fiber penetration	2020	2022	2025

5) Grade of service

We define grade of service (GoS) as the percentage of time for which a user misses to get the promised bit rate. For the analysis, we have considered a GoS of 0.1 %.

6) Results

Considering the above parameters and using the assumptions outlined above, the calculated line rate per street for upcoming years is shown in Figure2. Note that the line rate was calculated using Eq (4) and making other assumptions as discussed above. It can be seen that in the dense urban scenario, a line rate of around 143 Gbps will be required per street by the year 2027 and may remain below 100 Gbps for urban and rural scenarios.

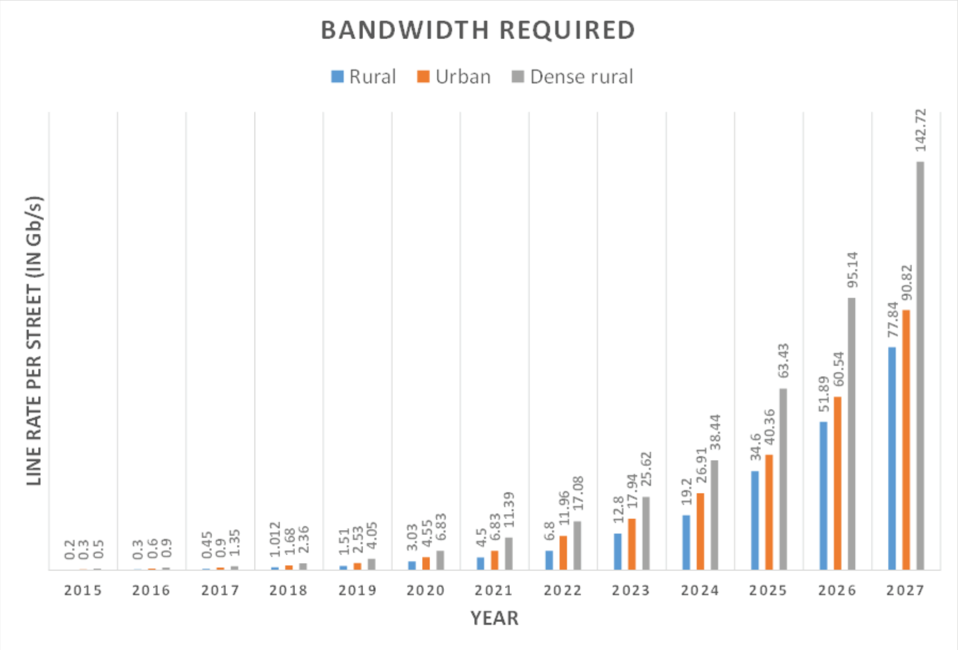

Figure 2: Line rate (per street) increase with year for different scenarios

III. Estimation of number of fibers required

The most critical cost factor in the FTTH network deployment is the capital expenditure incurred in digging trenches. The fiber deployment has to be adequately optimized considering several key factors:

1. The statistics of the area to be served, including household income, family size, and age distribution. This helps in generating the market opportunity for the sustainable service operation. In general, more favorable the statistics are, the deeper will be the fiber deployed.
2. The geography and topology of the service area, including the household density (average lot size), the Rights of Way (RoW) available, and whether cabling is underground or above

ground. This data is required for setting the cost of each approach. If these characteristics are poor, the challenges of a profit margin occur. Even a factor like whether the terrains are hilly or flat can have a critical impact on the deployment cost.

3. The fusion of services to be provided, over at least a period of fiveyears, considering both drifts in demand and competition. The most unfavorable case in the access fiber deployment is when the deployed fiber cannot support a new set of requirements.

Thus, it is of a paramount importance that fiber deployment is planned properly. A critical parameter that is required in fiber deployment is to estimate the lengths of fiber required. In this white paper, we estimate the typical fiber lengths that are required to serve a given geographical region and model the relation of fiber lengths to the technology used (point-to-point vs. point-to-multipoint) and the population density. In addition, fiber length is also a strong function of geospatial data; however, it is difficult to quantitatively estimate this, so we use simple geometric models.

We first discuss the basic optical access network architecture. In a typical optical access network architecture, an optical network unit at a subscriber's end is connected to an optical line terminal at the central office, through an optical distribution network composed of different fiber segments and remote nodes, cf. Figure 3. In the uplink (toward core) direction, an optical line terminal is connected to an aggregation network.

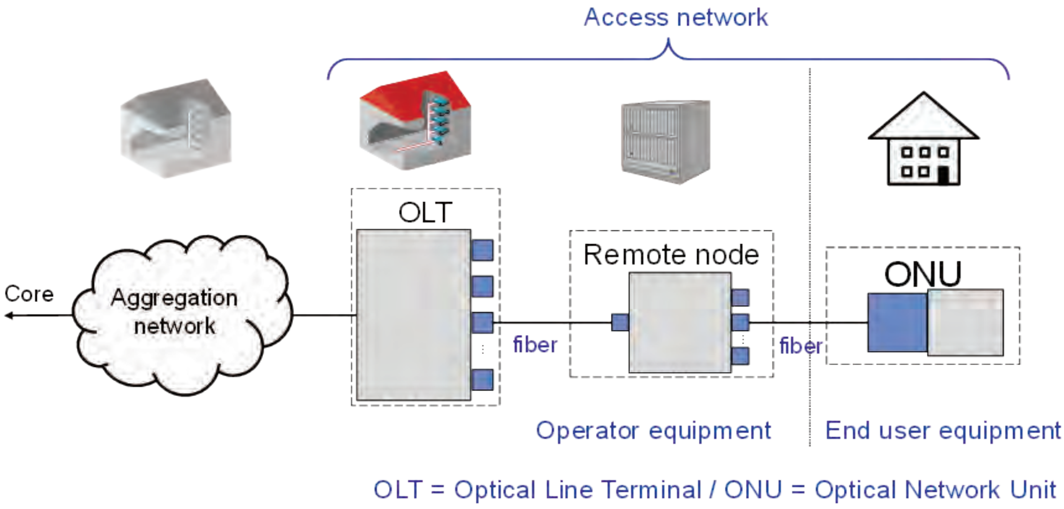

Figure 3: Optical access network

Optical access networks can use different multipoint topologies. The most common architecture, however, is based on a tree topology, with the optical line terminal as the root of the tree and the optical network units as the leaves.

Furthermore, there are three main categories of optical access networks (Figure 4): home run, active and passive. The simplest architecture is home run or point-to-point (P2P) fiber architecture, which offers a dedicated fiber from the central office to each home user. In the case of an active optical network, a switch or router is installed between the central office and the user, and from this point, a dedicated fiber reaches each user. On the other hand, passive optical networks use passive splitters/combiners instead of the active switch. Both active optical networks and passive optical networks are point-to-multipoint networks.

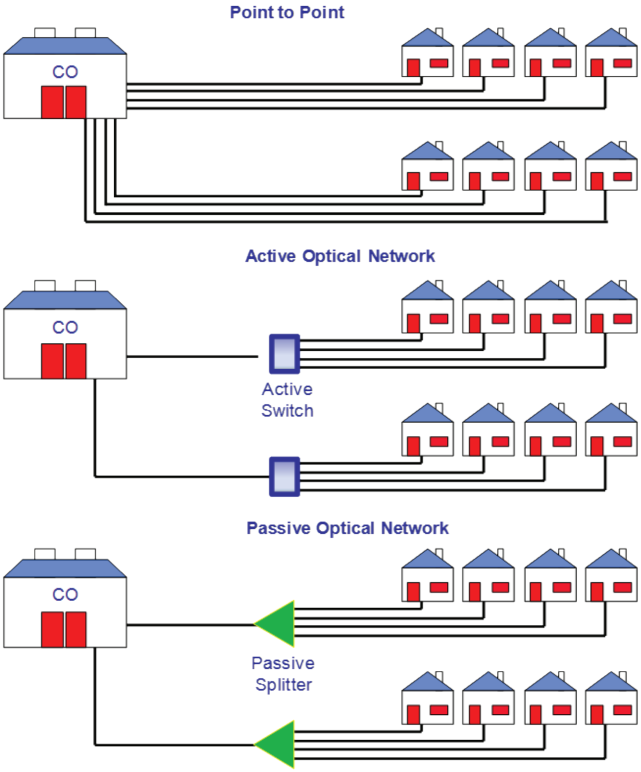

Figure 4: Optical access network architectures

The goal of the study is to estimate the number of fibers required, first for the point-to-point topology and then for the point-to-multipoint topology. It is clear from the onset that the number of fibers required in point-to-point topology will be much higher than that required in point-to-multipoint topology.

1) Point-to-point

For estimating the number of fibers required, several models are used in the literature – like triangle method, simplified street length model, and geospatial models. For the illustration of the present scenario, we use the simplified street length model (cf. Figure 5). In this model, we assume that the central office (CO) is always situated in the middle of the square and that the customer base is uniformly distributed over a squared area. All streets are connected using one divider-street and all houses are connected in one line through the middle of the house.

One side of the square contains NB buildings and the distance between two buildings is indicated by a distance l. Further, we assume that the number of houses per building is k, and thus the total number of households can be given as k×NB.

We have used three scenarios: dense urban, urban and rural. The parameters used for different scenarios are presented in Table 2.

In the first case, we assume a point-to-point technology.

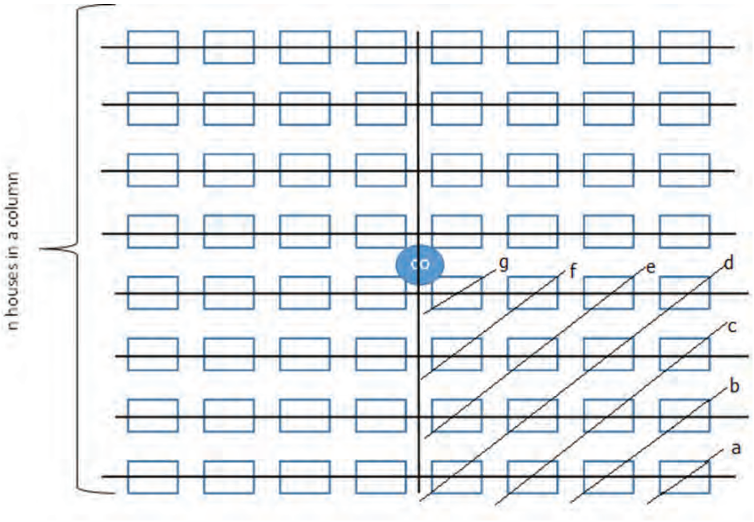

Figure 5: Schematic of a simplified street length model.

Let *l* be the distance between two houses and there are *n* houses in a row and a column, then each row of houses need a trench of $(n-1)l$ length and number of rows are also *n*. So now length becomes $n(n-1)l$. Trenching length for divider street is $(n-1)l$. Hence, total trenching length is given as

$$L_{FT} = n(n-1)l + (n-1)l = (n^2-1)l \quad (6)$$

For calculating feeder fiber length, symmetric structured model is assumed with the central office dividing the structure into four equal quadrants as shown in Figure 5. Considering one quadrant, lengths are calculated by dividing houses in different categories: $a = (n-1)l, b = (n-2)l, \dots, g = l$. So number of houses per category first increases and then after crossing half the quadrant, decreases with each step. Let *k* gives the number of households (N_H) per building (N_B) i.e. $k = N_H/N_B$ as an independent fiber is required per household. The total feeder fiber length considering above facts is given as [7]

$$L_{FF} = 4lk \sum_{i=1}^{n-1} [\min(i, n-i) \times (n-i)] \quad (7)$$

Average number of fiber per trench (N_F) can be computed as:

Average number of fiber per trench (N_F) can be computed as:

$$N_F = L_{FF}/L_{FT} \tag{8}$$

Together with this, we assume that 20% more fibers will be needed for protection, and OAM.

Table 2 contains various parameters considered for calculating the average number of fibers per trench. We have considered three different demographic scenarios: dense urban, urban and rural. For a point-to-point technology, the average number of fibers per trench varies from 242 in a dense urban scenario to 174in case of an urban scenario, and to 33 in a rural scenario (cf. Table 2).

Table 2: Considered parameters for different scenarios considering point-to-point topology

	Dense Urban	**Urban**	**Rural**
Building density (1/Km^2)	560	470	430
Area (km^2)	5.89	6.51	7.21
Average number of household per building	7.1	5.3	1.0
Total fiber length	27,773 km	20,330 km	4,010 km
Total trench length	137 km	139 km	145 km
Average fiber length per household	1.18 km	1.24 km	1.29 km
Average number of fiber per trench	202	145	28
Average number of fiber per trench including OAM and protection	242	174	33

2) Fiber length in Point-to-Multipoint technologies

In point-to-multipoint technologies, an optical line terminal is shared among multiple users. Typically, the architecture of a point-to-multipoint topology consists of an optical line terminal connected by a remote node through a feeder fiber and the remote node is connected to several users by distribution fibers. Thus, in this case, every user does not have a direct fiber between an OLT and a user. Different multiple access technologies like time division multiple access can be used to share the feeder fiber. As the feeder fiber is shared, the length of the fiber required can be reduced. We calculate the length of the feeder fiber required according to three different split ratios of 16, 32 and 64. We assume that the feeder fiber length is 84% of the total fiber length, and that the feeder fiber is protected but distribution fibers are not. Feeder fiber protection is generally required as a feeder fiber cut affects many users simultaneously, whereas a distribution fiber cut affects only a single user. This impact is also measured by a failure impact factor. We further assume that we have 10% spare fiber for OAM.

The total fiber length in a point-to-multipoint technology can be estimated as:

$$10\% \times FL \times \left(\frac{2 \times f_r}{r} + 1 - f_r \right) \tag{9}$$

where *FL* is the total fiber length as calculated in the point-to-point technology, *r* is the split ratio, f_r is the ratio of length of feeder fiber to distribution fiber. The essence of the above formulation can be understood as this - only the part of the total fiber length that is consumed by the feeder fiber is reduced due to sharing and thus r has an effect only the part of the length consumed by the feeder fiber, that is, $FL \times f_r$. A factor two is again multiplied on to the feeder fiber length as we assume feeder fiber protection. Also note that the total fiber length reduces by a factor 1/*r* and thus by having a slight increase in *r*, total fiber length reduces sharply.

Table 3: Typical parameters for dense urban scenario considering point-to-multipoint topology

Split ratios	16	32	64
Total fiber length	8,129 km	6,611 km	5,851 km
Average fiber length per household	0.35 km	0.28 km	0.25 km
Average number of fiber per trench	59	48	43

Table 4: Typical parameters for urban scenario considering point-to-multipoint topology

Split ratios	16	32	64
Total fiber length	5,950 km	4,839 km	4,283 km
Average fiber length per household	0.36 km	0.30 km	0.26 km
Average number of fiber per trench	43	35	31

Table 5: Typical parameters for rural scenario considering point-to-multipoint topology

Split ratios	16	32	64
Total fiber length	1,174 km	954 km	845 km
Average fiber length per household	0.38 km	0.30 km	0.27 km
Average number of fiber per trench	8	7	6

Even though the point-to-point topology consumes more fiber, a point-to-point technology promises the most future-proof bandwidth solution. As we have seen that in future the bandwidth demand can soar to very high limits, it is clear that current time division multiple access technologies will fail, and thus, either a point to point topology or wavelength division based multiple access technologies will be used in the future. Moreover, as the cost of the fiber is immaterial in comparison to the cost of digging and trenching, we recommend that a fiber-rich scenario assuming a point-to-point technology and a dense urban scenario can be deployed upfront.

Conclusion

In this paper, variations of different factors affecting bandwidth estimation such as number of users per street, bandwidth requirements per house, user activity, user density, and the required grade of service are discussed. Considering all these factors it is estimated that a line rate of 143 Gb/s is required to support the bandwidth demands of dense urban users and a line rate of 100 Gb/s (approximately) is required for urban and rural users. The year-wise growths in data rate requirements are also estimated in Figure 2. We further estimate the number of fibers per trench (the number of fibers are approximated as total fiber length per total trench length). For this, we consider a simplified street length model for estimating distribution of buildings. We consider two different topologies: point-to-point and point-to-multipoint. As the fiber cost is negligible in comparison to the cost of digging and trenching, it is recommended that approximately 250 fibers can be deployed per trench considering a point-to-point technology and dense urban scenario as it guarantees the most future proof bandwidth solution. The expected number of fibers per trench for different scenarios (dense urban, urban, and rural) are given in Table 6.

Table 6: Average number of fiber for different split ratios and different population density scenarios

Split ratios	**1**	**16**	**32**	**64**
Dense urban	242	60	49	43
Urban	174	43	35	31
Rural	33	8	7	6

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