

Comparative Cost Study of Broadband Access Technologies

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Abstract—This paper provides a simple techno-economic study of various access network technologies for broadband data service delivery, including their deployment cost analysis. This study compares the deployment cost per unit bandwidth of different access technologies from a city perspective and can serve as a guideline for future access network deployment in the urban area.

I. INTRODUCTION

Optical backbone networks have experienced a significant increase in capacity. Data can be carried at Tbps bandwidth across long distances. However, carrying information to the residential customer still depends on legacy low-bandwidth access networks. It has been predicted that the per-home bandwidth demand will increase to as high as 70 Mbps in the future [1]. Existing access network technologies such as Digital Subscriber Line (xDSL), Cable Modem, Wireless and Cellular data services, etc. do not come close to meeting this demand. FTTX (*fiber-to-the-X*) technology is expensive today although it can provide much higher bandwidth to both residential and business customers. Hence, its deployment is limited to a small portion of urban areas. Consequently, the residential access network infrastructure remains as a major obstacle for the deployment of a broadband telecommunications network [1].

There are several access technologies proposed and deployed in the market. Which one is most suitable for future broadband access? The selection of technology depends on customer demand characteristics and existing infrastructure issues.

In this paper, we provide a cost analysis for deploying various access technologies in a city area. The study considers the options that are likely to be prevalent in the foreseeable future. We take the city of Davis (in Northern California) as an example for the deployment cost assessment. Davis has a nice blend of competitive market segments in the downtown area and bandwidth-savvy residential customers. This work enables us to establish a guideline for broadband access upgrade strategies.

II. BROADBAND ACCESS TECHNOLOGIES

Today, there is a broad range of access technologies readily available for upgrade. The enhanced copper or xDSL systems cover various technologies such as asymmetric DSL (ADSL), very-high-speed DSL (VDSL), and high-bit-rate DSL (HDSL). xDSL technologies use existing Public Switched Telephone Network (PSTN) infrastructure to provide broadband service, and the claimed peak bandwidth for this technology is up to 10 Mbps. Cable modem technology uses co-axial cable to provide Internet service along with digital TV. The peak bandwidth is up to 30 Mbps (as claimed) [1]. Wireless access technologies such as Wireless Fidelity (WiFi) (peak bandwidth

54 Mbps), Worldwide Interoperability for Microwave Access (WiMAX) (peak bandwidth 100 Mbps), and Cellular data service (peak bandwidth 10 Mbps) [1] are candidates for future access alternatives.

FTTX option is expensive but provides bandwidth in the Gbps range. Passive Optical Network (PON) is the leading choice for fiber access network deployment because it has only passive elements in the fiber plant. A PON segment is headed by an Optical Line Terminal (OLT) which drives several Optical Network Units (ONU) which in turn serve end-users. Hybrid Wireless-Optical Broadband Access Network (WOBAN) is a novel broadband access architecture which captures the best of both the optical and wireless worlds. WOBAN consists of a wireless network at the front-end supported by an optical backhaul, and can provide high bandwidth [3].

The access technologies that are considered in this paper are: (1) xDSL Technologies, (2) Cable Modem, (3) FTTX (Fiber Options) (4) WiFi Wireless Access, and (5) WOBAN with WiFi and WiMAX. Broadband radio alternatives, satellite-based alternatives, and cellular data service are not considered mainly due to lack of deployment-cost information; also the alternatives considered seem to be the leading choices today.

Map of Population density (people per square mile)2000 in Davis, CA

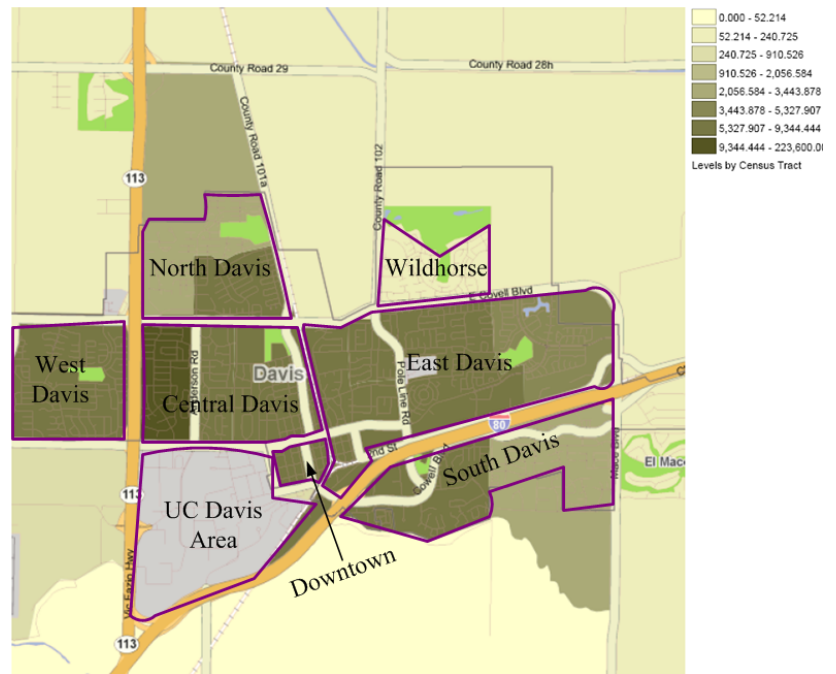


Fig. 1. Davis population density map (Courtesy: DataPlace [2]).

III. CASE STUDY: DAVIS PERSPECTIVE

To evaluate the cost and deployment issues, we consider a hypothetical broadband access deployment scenario in Davis, which is a small city in Northern California near Sacramento.

TABLE III
COMPONENT COSTS.

Component	Cost (in ONU units)
DSL Modem	0.3 [4]
Cable Modem	0.5 [4]
ONU	1 [3]
OLT	50 [3]
Fiber Installation cost (trenching + material + labor and installation)	1000/mile [3]
WiFi Routers	1 [5]
WiFi Gateway	3.5 [5]
WiMAX Base Station (BS)	300 [5]
WiMAX Customer Premise Equipment (CPE)	1 [5]

Davis is the home of the University of California, Davis. The UC Davis area in the City of Davis is excluded from our study because UC Davis has its own network infrastructure.

A. Davis Demography

According to the 2000 census, Davis has a population of 60,341 with 23,259 households, and average household size is 2.5 [2]. Figure 1 shows the map of population density in the Davis area. We can divide Davis into seven smaller zones. Using the data obtained from [2], we can estimate the population of each zone, as shown in Table I.

The downtown area has a rich variety of businesses. The area is approximately five blocks by five blocks. Each square block has around ten businesses which can employ broadband access. As a result, we need around 250 business connections in the downtown area for broadband access deployment.

TABLE I
DAVIS POPULATION DATA.

Zone	Area Size (sq. miles)	Approx. Population	Approx. Households
West Davis	0.8	7,800	3,000
North Davis	0.64	5,500	2,100
East Davis	1.76	12,900	5,300
Central Davis	1.2	24,400	9,600
Wildhorse	0.44	1,400	400
Downtown	0.175	2,000	600 + 250 offices
South Davis	0.86	6,000	2,250
Total	5.88	60,000	23,500

IV. DEPLOYMENT COSTS

Different access technologies require different sets of components for deployment (see Table II). By knowing the major

TABLE II
VARIOUS COMPONENTS FOR ACCESS NETWORK TECHNOLOGIES.

Technology	Major Components
xDSL	Twisted pair cable + DSL modem
Cable Modem	Coaxial cable + Cable modem
WiFi	WiFi routers + Gateways
Fiber Options (PON)	OLT + ONUs + OLT-to-ONU fiber + ONU-to-customer fiber
WOBAN	OLT + ONUs + WiFi/WiMAX routers + OLT-to-ONU fiber

components of various access technologies, we can quantify their expenses from various sources. Table III gives the estimated costs of major components for various access technologies. We normalize each component cost using the cost of an ONU (\$100) as a reference price, so each price is given in ONU unit. For our cost calculations, we assume the same data rate will be provided to both residential and business customers.

A. xDSL Technologies

It is our experience that almost all Davis houses have twisted-pair cabling and the entire city area is connected by POTS (Plain Old Telecommunication System). Therefore, there is no need to lay twisted-pair cables to provide xDSL service. Although it is claimed that xDSL can provide peak rate up to 10 Mbps, our experience in Davis area shows that the highest available bandwidth in approximately 2 Mbps. Hence, we use 2 Mbps as the average bandwidth for xDSL technologies during

our per-Mbps cost calculation later. To provide DSL service to all households in Davis, we need a DSL modem in each household. This will cost $23,500 \times 0.3 = 7,050$ ONU units.

B. Cable Modem

As in xDSL, almost all Davis households also have wiring for cable service. Therefore, we need to install one cable modem per home in the city. Again, although the claimed bandwidth is 30 Mbps for cable modem, our experience shows that it is around 6 Mbps in Davis area. So, the average bandwidth considered during our per-Mbps cost calculation later for Cable Modem technology is 6 Mbps. The total cost of deployment will be $23,500 \times 0.5 = 11,750$ ONU units.

C. WiFi

This option requires more effort to estimate the deployment cost. Total number of WiFi routers needed to provide a certain bandwidth to a service area is itself a planning problem. The scope of this report does not cover this problem. Therefore, we will use some empirical data available from the wireless mesh deployment initiatives in other cities. We consider two such initiatives – (a) Mountain View CA and (b) Corpus Christi TX – as these two cities are similar to Davis with respect to area. Google has implemented a wireless mesh in Mountain View, and the city of Corpus Christi used Tropos networking elements with the help of Pronto Networks to build its mesh [6]. Mountain View mesh has 400 routers covering 12 sq-miles while Corpus Christi pilot mesh covers 18.5 sq-miles with 300 routers [6]. From these wireless mesh deployments, it is found that, to provide a bandwidth of 2 Mbps in Mountain View, one needs to deploy 35-40 routers per sq-mile. Mountain View has population of 70,467 with population density of 5,860/sq-mile. These 35-40 routers will be driven by a gateway. Therefore, in our deployment scenario for Davis, we consider to deploy 40 routers and 1 gateway per sq-mile for a population density of 5,860/sq-mile (Reference Density (RD)). In the downtown area, to provide upto 2 Mbps of data rate to 250 offices, we need approximately 5 more routers (derived using RD data). Thus, the number of routers and gateways needed for each city zone in Davis are given in Table IV.

Therefore, our cost will be $406 + 13 \times 3.5 \approx 452$ ONU units to deploy WiFi mesh in Davis.

D. Fiber Options

In a typical PON, the OLT is located at the telecom Central Office (CO), and fiber is laid from OLT to the ONUs and from ONU to the customer premises. To deploy a PON, we assume that an OLT is placed in the city's (Davis) CO located

TABLE IV
WIRELESS COMPONENT ESTIMATES FOR CITY OF DAVIS.

Zone	Approx. Population Density	Approx. # of Wireless Routers	Approx. # of Gateways
West Davis	$2 \times RD$	64	2
North Davis	$1 \times RD$	26	1
East Davis	$1.37 \times RD$	96	3
Central Davis	$3.30 \times RD$	158	4
Wildhorse	$0.36 \times RD$	7	1
Downtown	$1.62 \times RD$	12+5 routers for offices = 17	1
South Davis	$1.1 \times RD$	38	1
Total		406	13

TABLE V
NUMBER OF ONUS REQUIRED FOR PON DEPLOYMENT IN DAVIS.

Zone	# of households	# of ONUs (2.5 Gbps)	# of ONUs (10 Gbps)
West Davis	3,000	84	21
North Davis	2,100	59	15
East Davis	5,300	149	37
Central Davis	9,600	269	68
Wildhorse	400	12	3
Downtown	600 households + 250 offices	24	6
South Davis	2,250	63	16
Total	23,500	660	166

in Downtown Davis. Optical fiber installation is expensive (USD 100,000 per mile in metropolitan area) [3], and it is reported that about 85% of this amount is tied to trenching and installing a new duct [3]. The rest (about 15%) of the expense involves the cost of new fiber and raw materials. In the US, an estimated 95% of localities are within 1-1.5 km of fiber-optic infrastructure [3]. Hence, we can assume that most of Davis is within the reach of fiber-optic ducts. Therefore, we do not need to lay totally new fiber from OLT to ONUs. On average, we will need to lay 0.5 mile of fiber to each ONU. Also, from the ONU to the customer (average 0.5 mile), new fiber duct needs to be trenched. We further assume that current ONU capacity is 2.5 Gbps, and in future, ONU capacity will reach 10 Gbps. Each user (residential/business) has a bandwidth demand of 70 Mbps. Using these data, we calculate the number of ONUs required to serve the city of Davis, as shown in Table V.

We have to lay on average 0.5 mile of fiber to each ONU. This requires additional cost of 500 ONU units (1000 ONU units/mile \times 0.5 mile) per ONU deployment. Therefore, at 2.5 Gbps ONU capacity, cost is $660 \times 500 + 660 = 330,660$ ONU units to take fiber from OLT to ONUs. At 10 Gbps ONU capacity, this cost will be $166 \times 500 + 166 = 83,166$ ONU units. We also need to lay last 0.5 mile of fiber to each household. This requires additional $23,500 \times 500 = 11,750,000$ ONU units, giving us total cost of $11,750,000 + 330,660 = 12,080,660$ ONU units at 2.5 Gbps, and $11,750,000 + 83,166 = 11,833,166$ ONU units at 10 Gbps.

E. WOBAN

We can employ either WiFi or WiMAX technology as the wireless front-end and PON as optical backhaul of WOBAN [3]. The deployment cost of the PON segment in WOBAN is similar to fiber (PON) option's OLT to ONUs cost. However, instead of laying fiber from ONU to the customer premises, WOBAN uses wireless access. Therefore, we need to calculate

TABLE VI
ACCESS TECHNOLOGY DEPLOYMENT COSTS FOR CITY OF DAVIS.

Options	Current Cost (per Mbps) (ONU unit)	Future Cost (per Mbps) (ONU unit)
xDSL	0.15	-
Cable Modem	0.083	-
WiFi	0.0096	-
Fiber options	7.34	7.19
WOBAN (with WiFi)	0.27	0.075
WOBAN (with WiMAX)	0.15	0.046

the last-hop (from ONU to the customer) deployment cost and add it with the OLT to ONU deployment cost (which is already calculated in the fiber option deployment). This will give us the total cost of WOBAN deployment at Davis.

If we deploy WiFi mesh for WOBAN front-end, we need to have a wireless router in each customer premise. The deployment cost of wireless routers in all these premises will be $23,500 \times 0.5 = 11,750$ ONU units (one wireless router costs 0.5 ONU unit). Therefore, the total deployment cost of WOBAN with WiFi mesh will be $330,660 + 11,750 = 342,410$ ONU units (at 2.5 Gbps ONU capacity). At 10 Gbps, the total deployment cost of WOBAN will be $83,166 + 11,750 = 94,916$ ONU units.

Similarly, if we use a WiMAX front-end in WOBAN, we need to deploy WiMAX Base Stations (BS) and WiMAX Customer Premise Equipments (CPE). For each population zone in Davis, we assume to deploy one WiMAX BS. Each customer premise will have one CPE. Therefore, the total deployment cost will be $330,660 + 7 \times 300 + 23,500 = 356,260$ ONU units (at 2.5 Gbps). At 10 Gbps, the total deployment cost will be $83,166 + 7 \times 300 + 23,500 = 108,766$ ONU units.

V. DISCUSSION AND CONCLUSION

Table VI summarizes our findings in this cost analysis. The "Current Cost" is calculated using the currently-available bandwidth for different technologies while the "Future Cost" (per Mbps) is obtained using future attainable bandwidth. We observe that for lower bandwidth demand (less than 2 Mbps), WiFi mesh is a cost-effective solution. However, for moderate bandwidth (around 5 Mbps), Cable Modem technology may be suitable. In future, xDSL, Cable Modem, or WiFi will not be able to meet the demands of bandwidth-savvy users. Therefore, future costs for these technologies have not been presented. The future bandwidth demand per household would grow to around 100 Mbps. Then, WOBAN with WiMAX front-end would be a cost-effective solution. For higher bandwidth, FTTX will be the only broadband access option. However, the initial cost of fiber deployment will be high compared to other access technologies. WOBAN with WiMAX will give cheaper bandwidth in future when WiMAX capacities are expected to reach 1 Gbps [3].

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