“Broadband Technology Roadmap for Rural Areas in the Andes and Amazon Regions in Peru”

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Agenda

1. Introduction
2. Research methodology
3. Technical analysis results
4. Engineering cost analysis results
5. Policy implications & technology roadmap
6. Conclusions

1. Introduction

Research Question

- **Research Question**

  "What is the technology roadmap for introducing broadband services to underserved and unserved areas in the Andes and Amazon Regions of Peru?"

Research Hypotheses

- **Hypothesis 1**

  *Deploying wireless access networks in the Andes and Amazon regions of Peru using the **Wi-Fi technology** and unlicensed spectrum has the **lowest deployment and operating cost** in a **10-year period**.*

- **Hypothesis 2**

  *Wireless access networks using **stratospheric platforms** in the Andes and Amazon regions of Peru has the **lowest deployment and operating cost** for the **initial years** but are **not able to scale** for a **10-year period** to serve forecasted customer and speed growth.*

- **Hypothesis 3**

  ***Spectrum management and regulation** have a quantifiable **technology and economic impact** in the deployment and operation of wireless access networks in the Andes and Amazon regions of Peru and are important to define the **best technology fit** to introduce broadband services in these regions.*

2. Research Methodology

Research Methodology

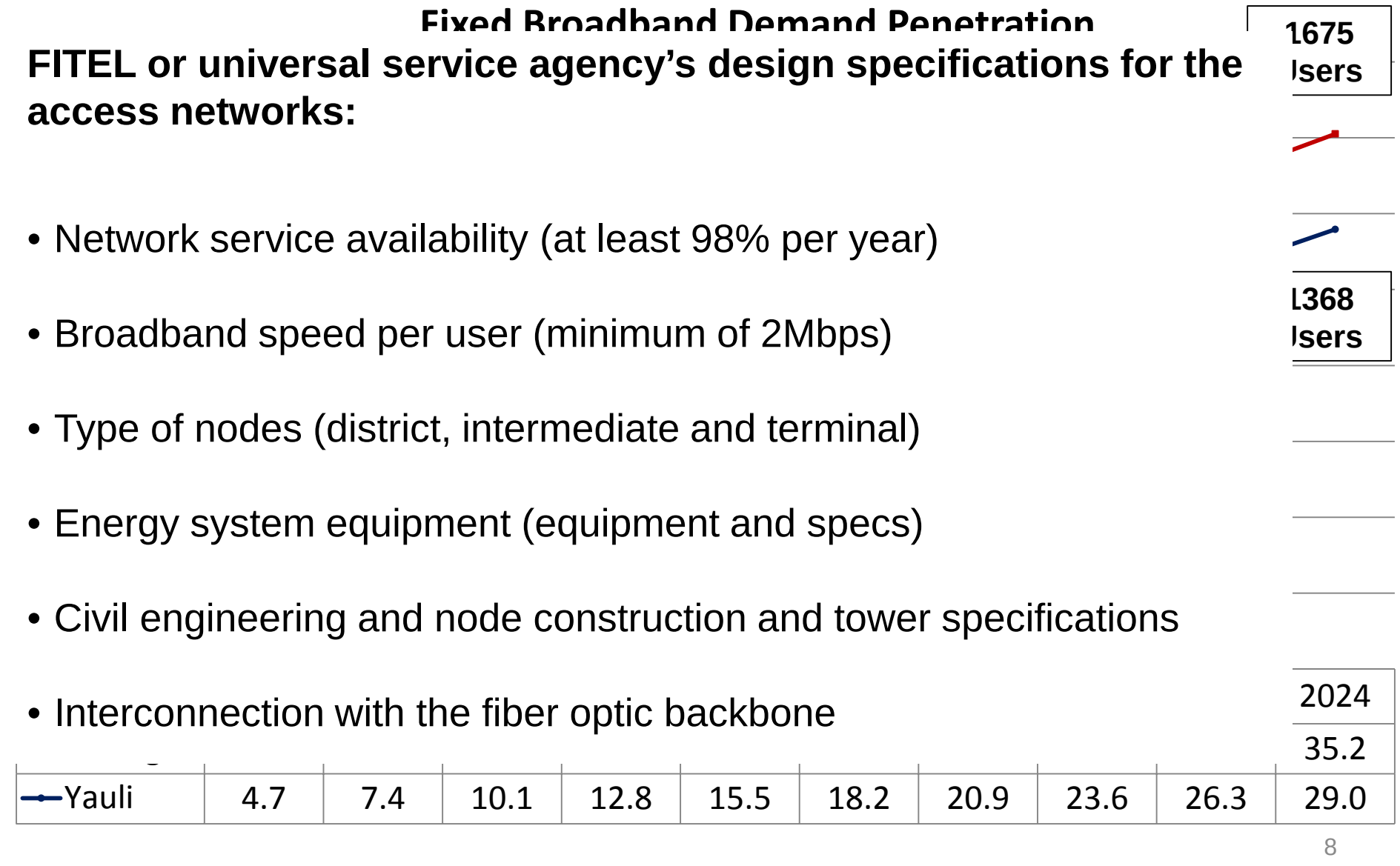
Analyzed Technologies

Technology	Band	Access Network	Max Rate	Eff. DL CH Capacity
LTE	1.7/2.1GHz (AWS)	Terrestrial	75Mbps (2Sx10MHz)	50-54Mbps
WiFi **IEEE 802.11n**	2.4GHz	Terrestrial	150Mbps (2Sx20MHz)	45-51Mbps
WiMAX **IEEE 802.16d/e**	3.5GHz	Terrestrial	75Mbps (2Sx10MHz)	45-51Mbps
TVWS **IEEE 802.22**	470-608MHz 614-698MHz	Terrestrial	16Mbps (1Sx6MHz)	10-11Mbps
LTE	1.7/2.1GHz (AWS)	Stratospheric Balloons	75Mbps (2Sx10MHz)	50-54Mbps

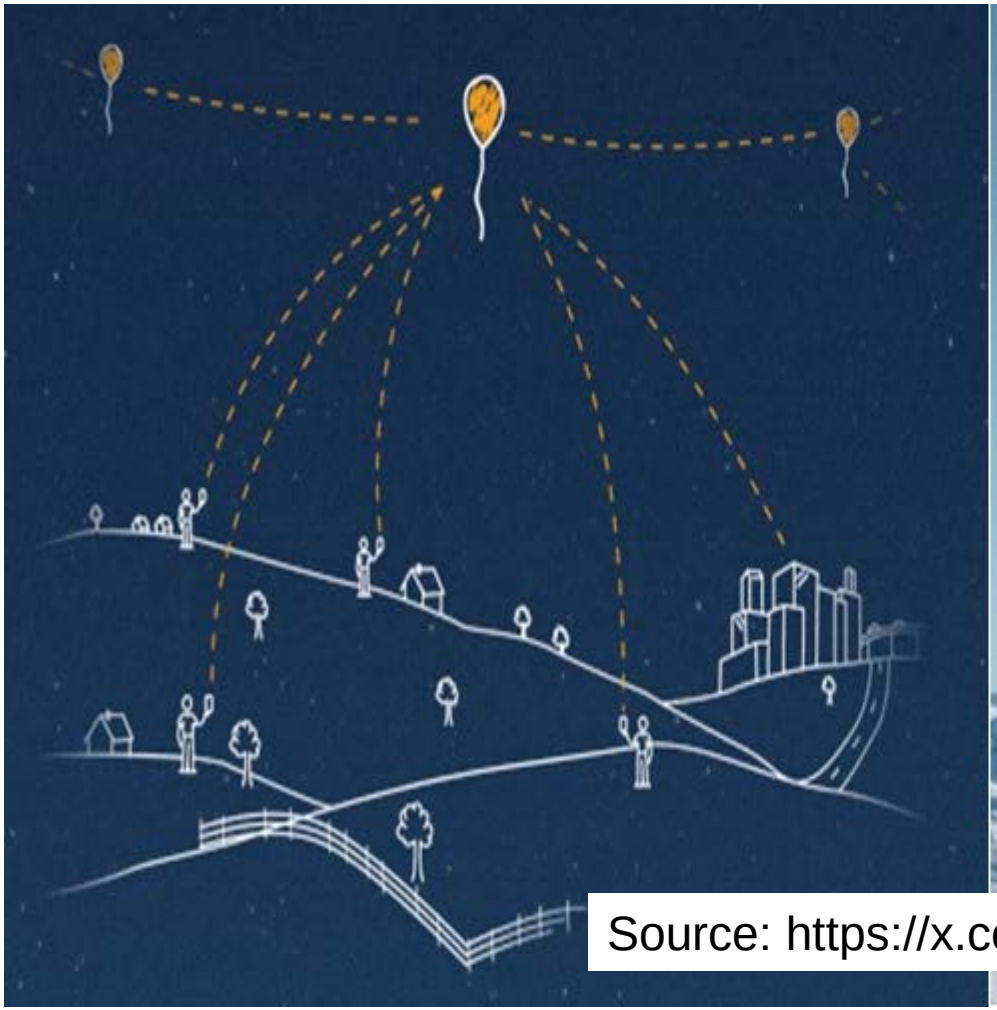
Residential Internet Penetration 2014

FITEL or universal service agency's design specifications for the access networks:

- Network service availability (at least 98% per year)
- Broadband speed per user (minimum of 2Mbps)
- Type of nodes (district, intermediate and terminal)
- Energy system equipment (equipment and specs)
- Civil engineering and node construction and tower specifications
- Interconnection with the fiber optic backbone



Stratospheric Balloons: Project Loon



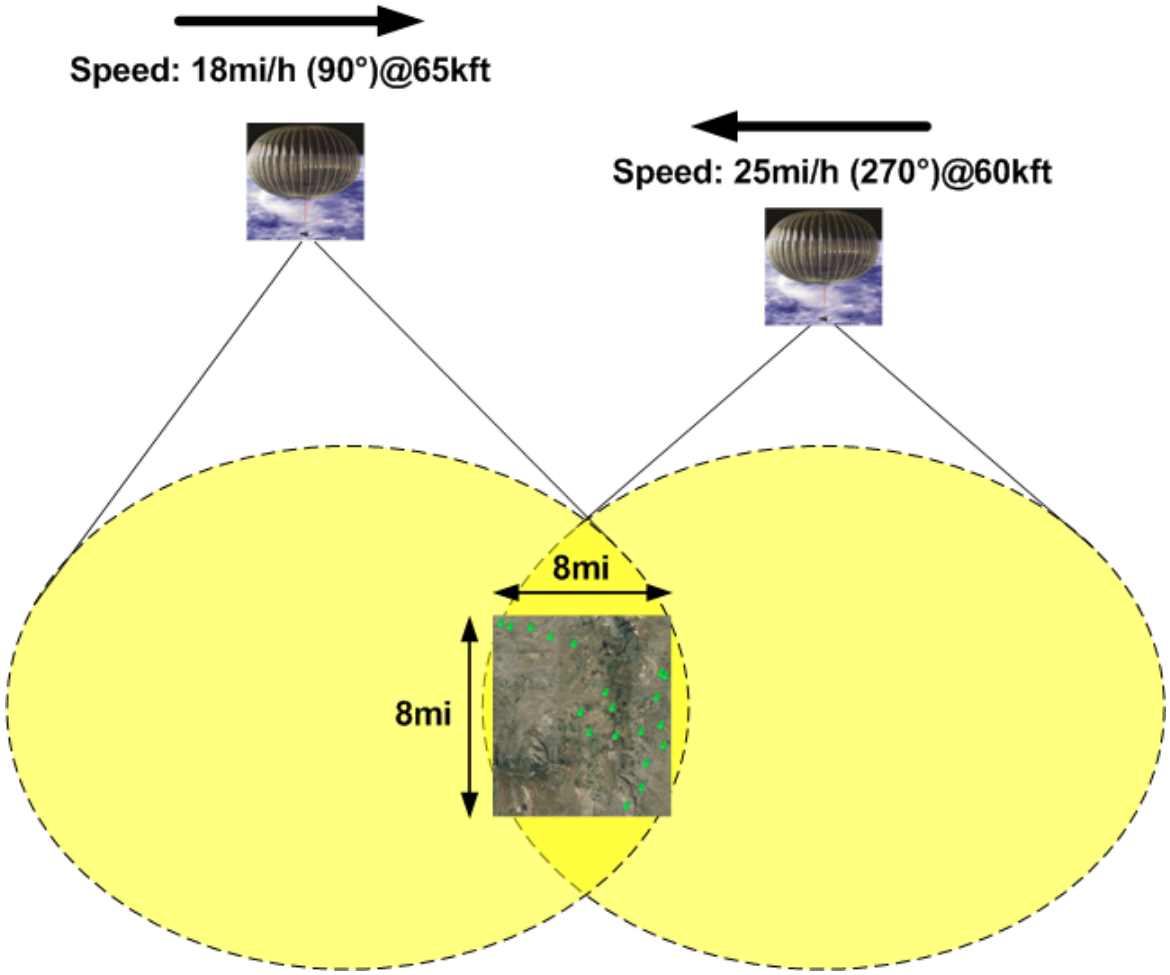
Source: https://x.company/loon/

Stratospheric Balloons: Project Loon

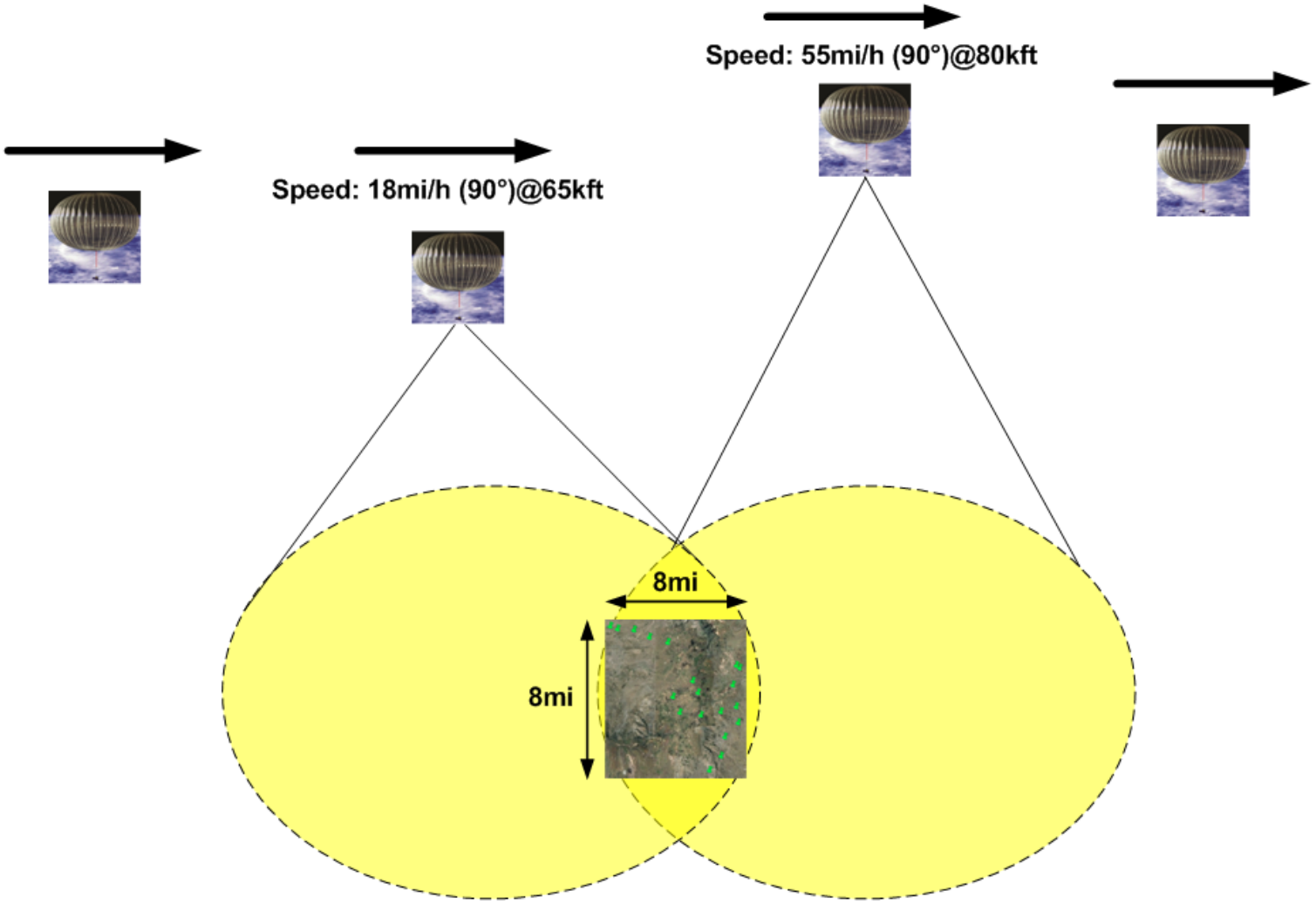
Estimated cost per balloon system

Computational Subsystem	$320.00
Solar Energy Subsystem	$6,972.00
Navigation subsystem	$8,325.00
Sensing Subsystem	$119.20
Altitude Control Subsystem	$493.40
Payload case	$795.60
Envelope, Gas & Parachute	$9,100.00
Other Accessories (15%)	$3,918.00
Telecom Subsystem 2: RF Access Link To Client Devices (approx. 10Mbps)	$23,076.77
Telecom Subsystem 3: RF Access Link To Backbone (approx. 10Mbps)	$3,982.38
UAS Assembly & Integration (15%)	$8,565
Total Cost	**$65,668.60**

Flight Configuration: Single Balloon



Flight Configuration: Balloon Constellation



Balloons Flight Patterns

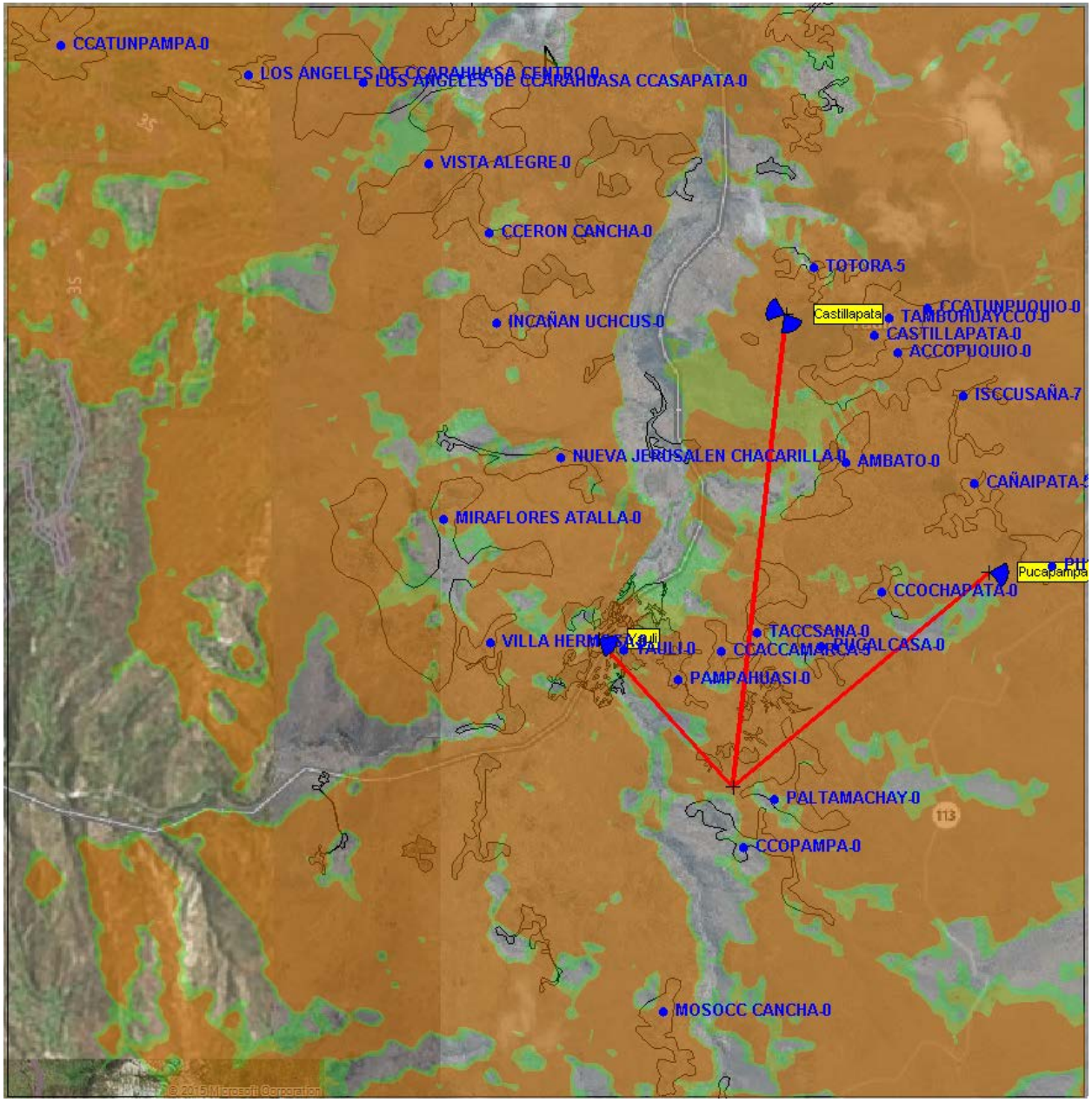
3. Technical Analysis Results

Yauli Area

(Andes Region)

LTE Technology

- Year 1 to Year 3
- 2Mbps

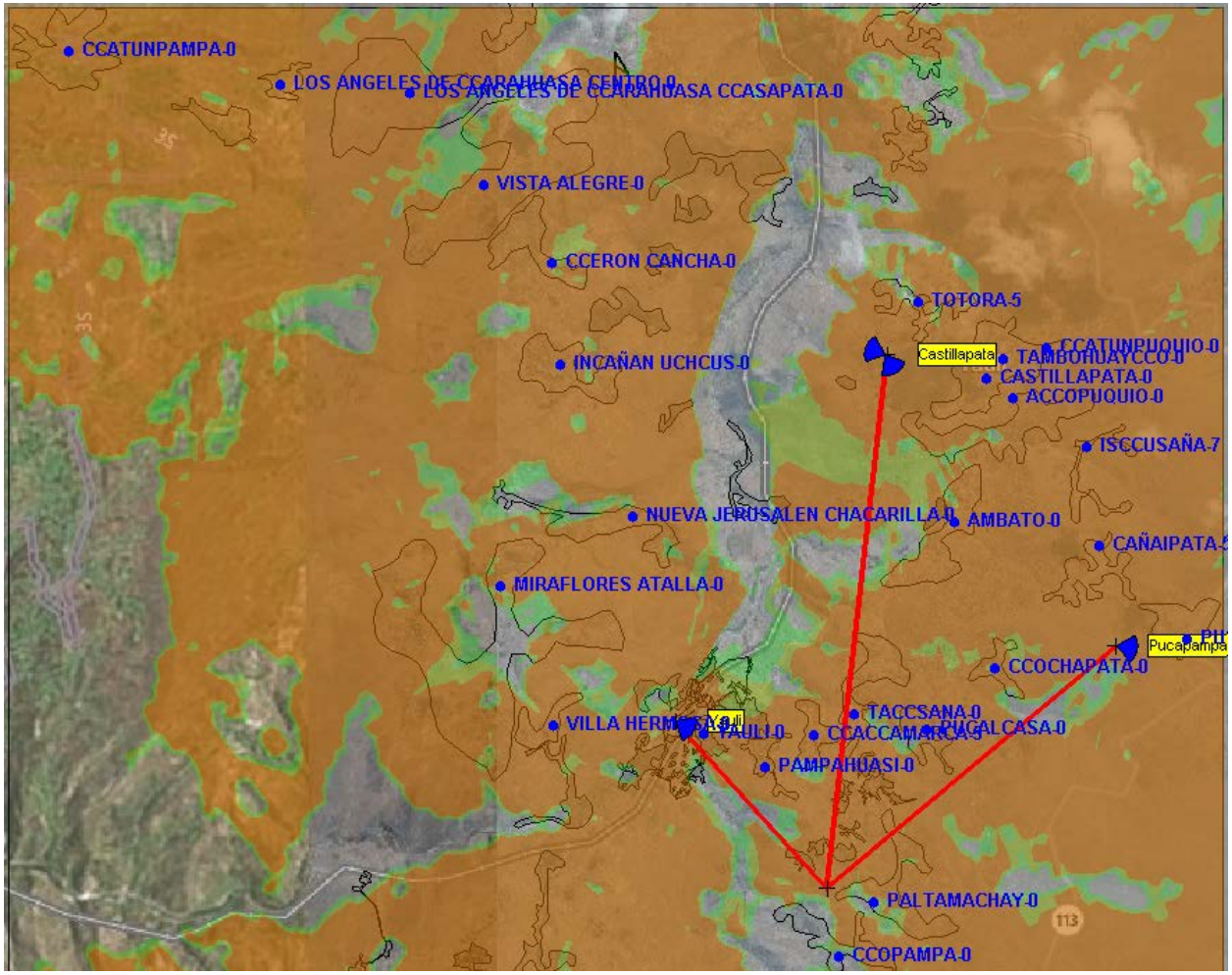


Yauli Area

(Andes Region)

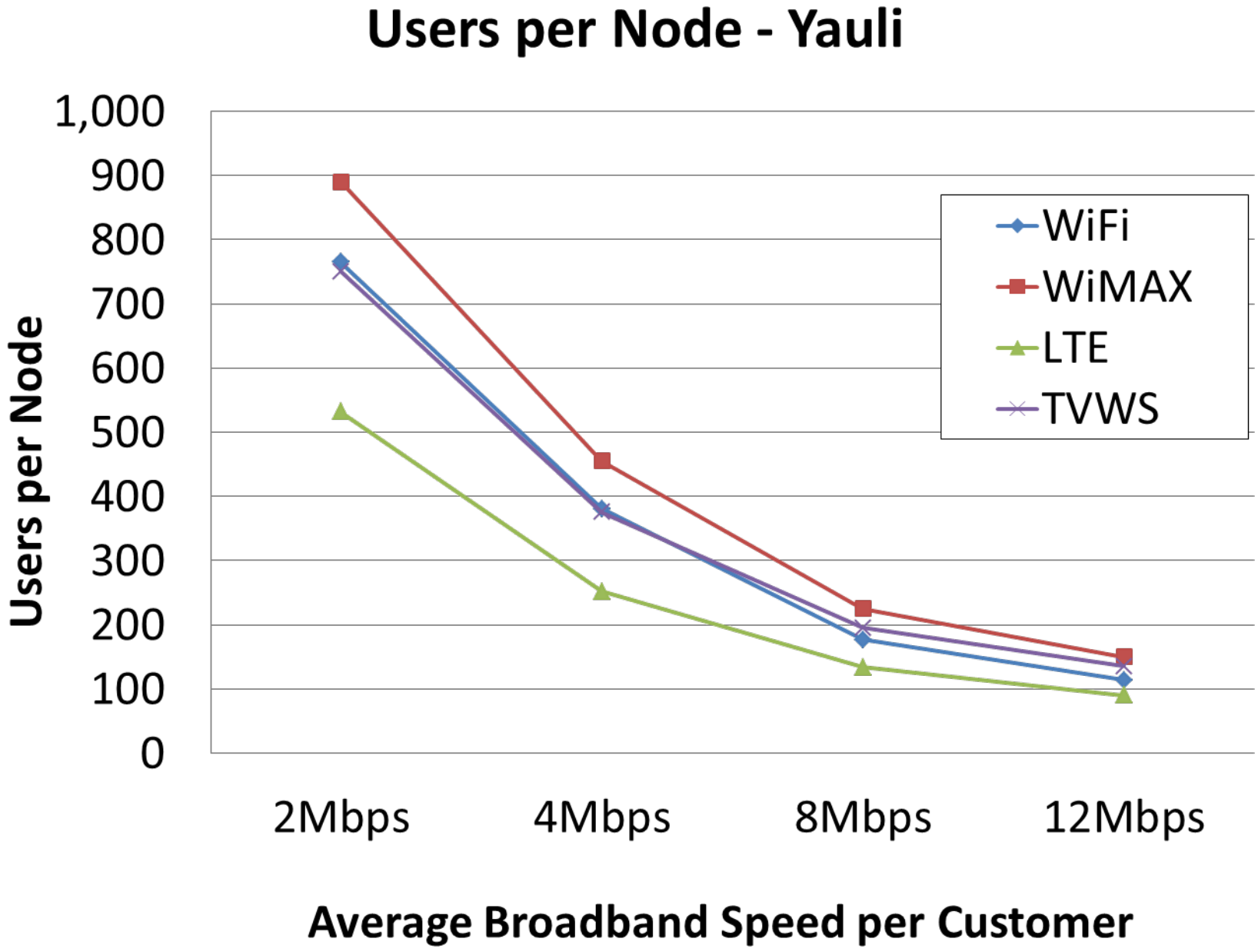
LTE Technology

- Year 1 to Year 3
- 2Mbps



$$\text{Effective Download Channel Capacity} = \sum_{Data\ Rates} (Data\ Rate\ Users * Actual\ Throughput)$$

$$\text{Capacity per Node} = \frac{Eff.Download\ Channel\ Capacity * \#\ Channels * Overbooking}{Average\ Speed\ per\ User}$$

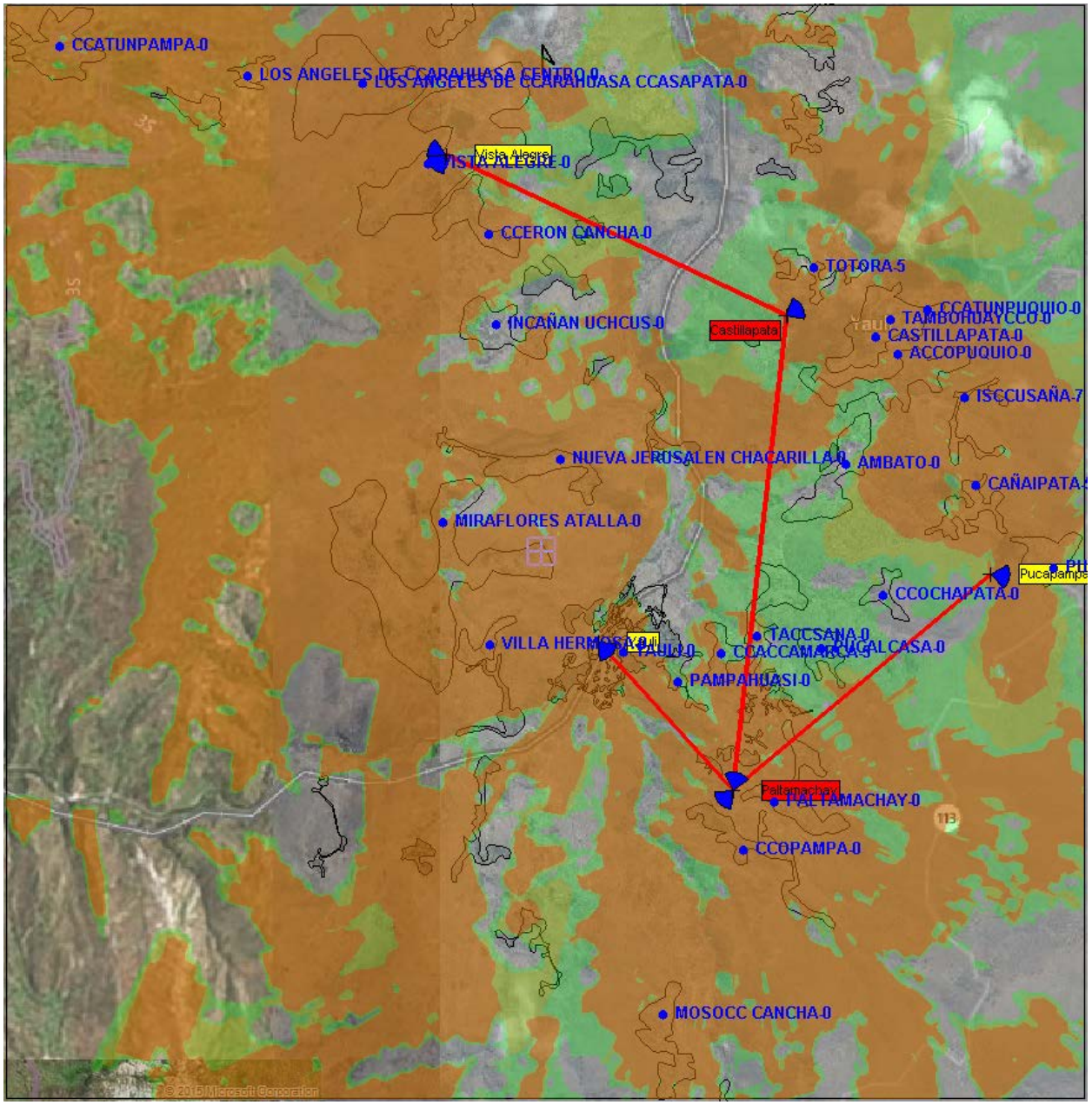

Users per Node - Yauli
1,000
900
800
700
600
500
400
300
200
100
0
Users per Node
WiFi
WiMAX
LTE
TVWS
2Mbps
4Mbps
8Mbps
12Mbps
Average Broadband Speed per Customer

Yauli Area

(Andes Region)

LTE Technology

- Year 4 to Year 7
- 4Mbps

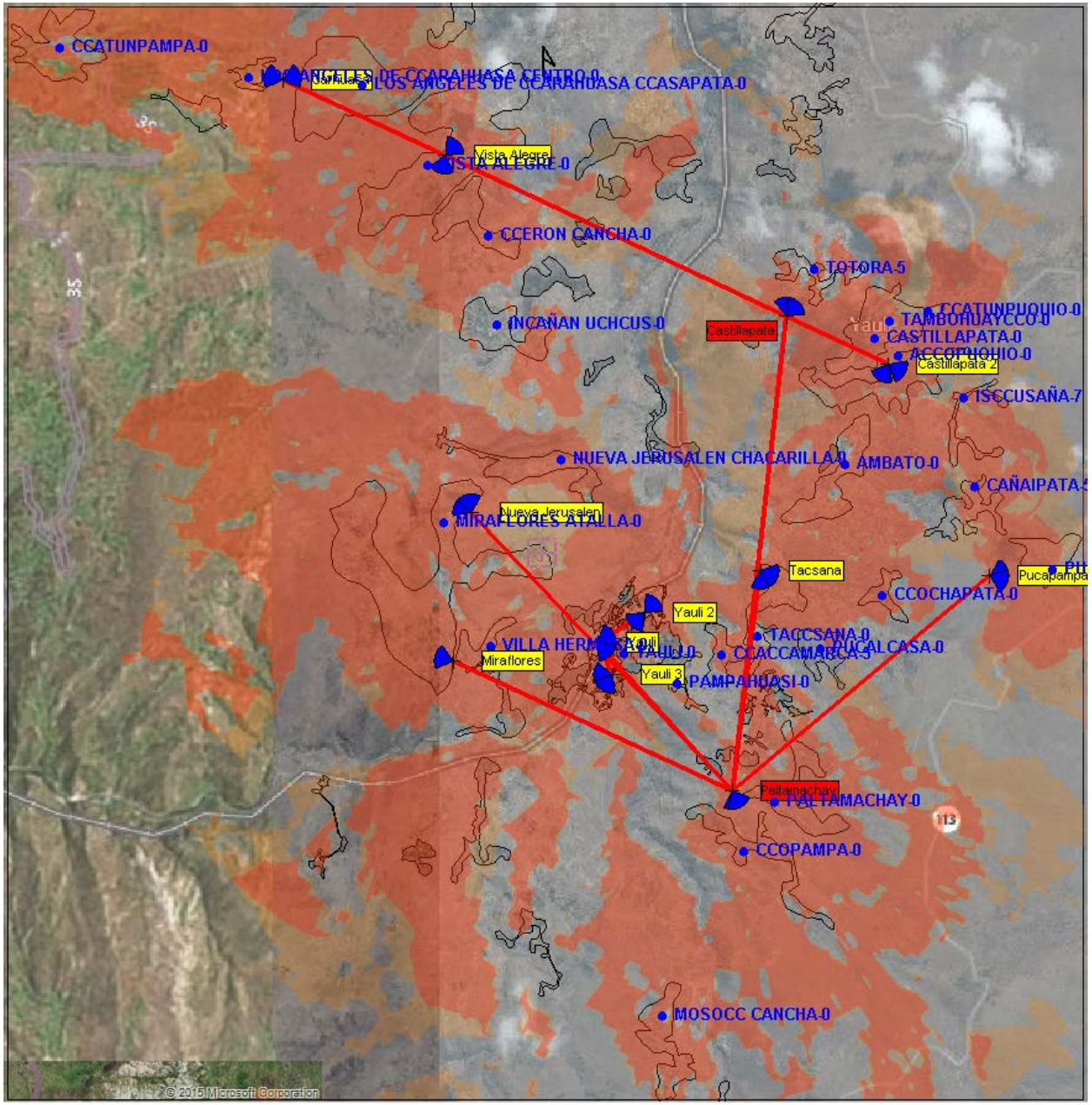


Yauli Area

(Andes Region)

LTE Technology

- Year 8 to Year 9
- 8Mbps

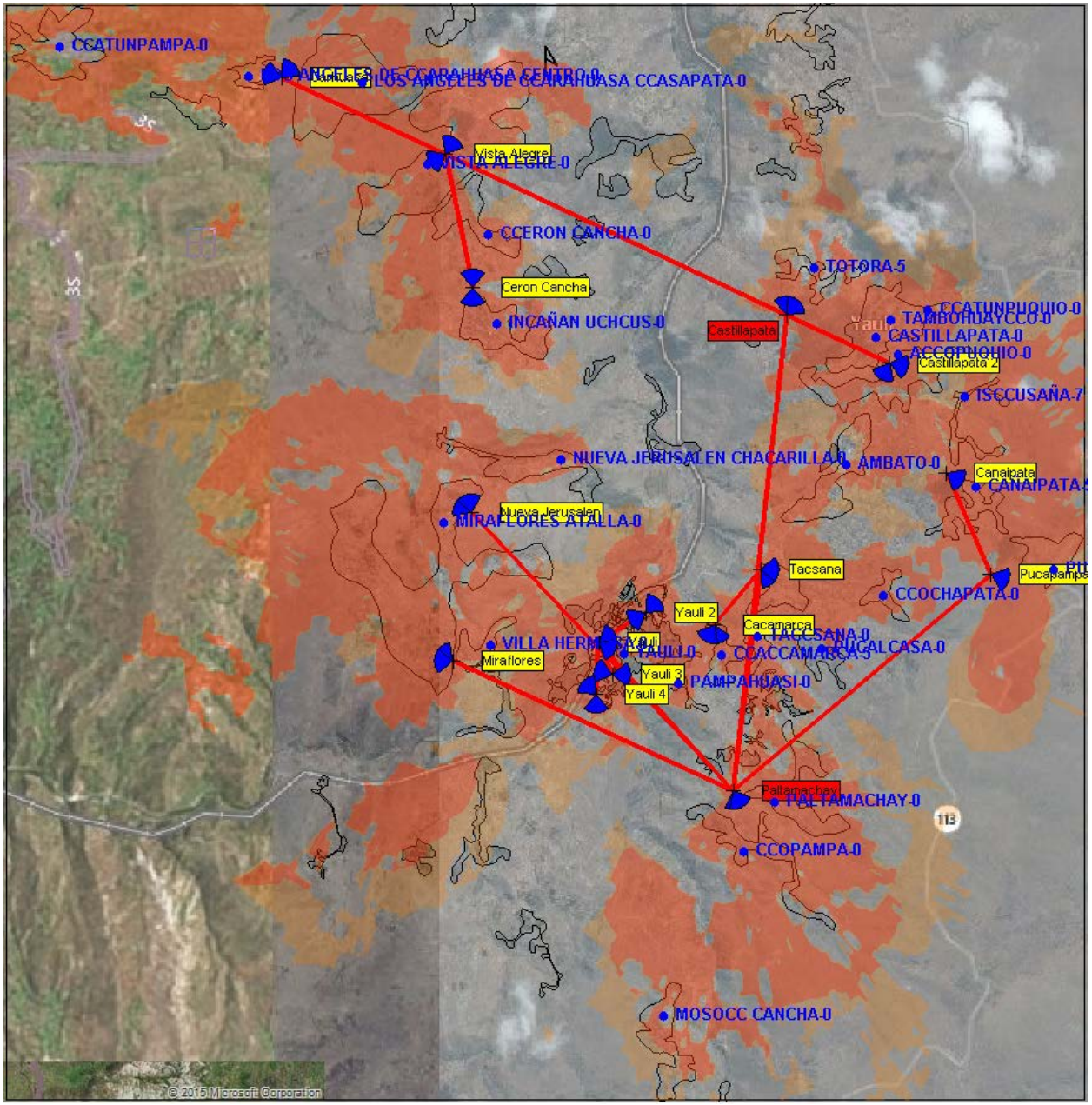


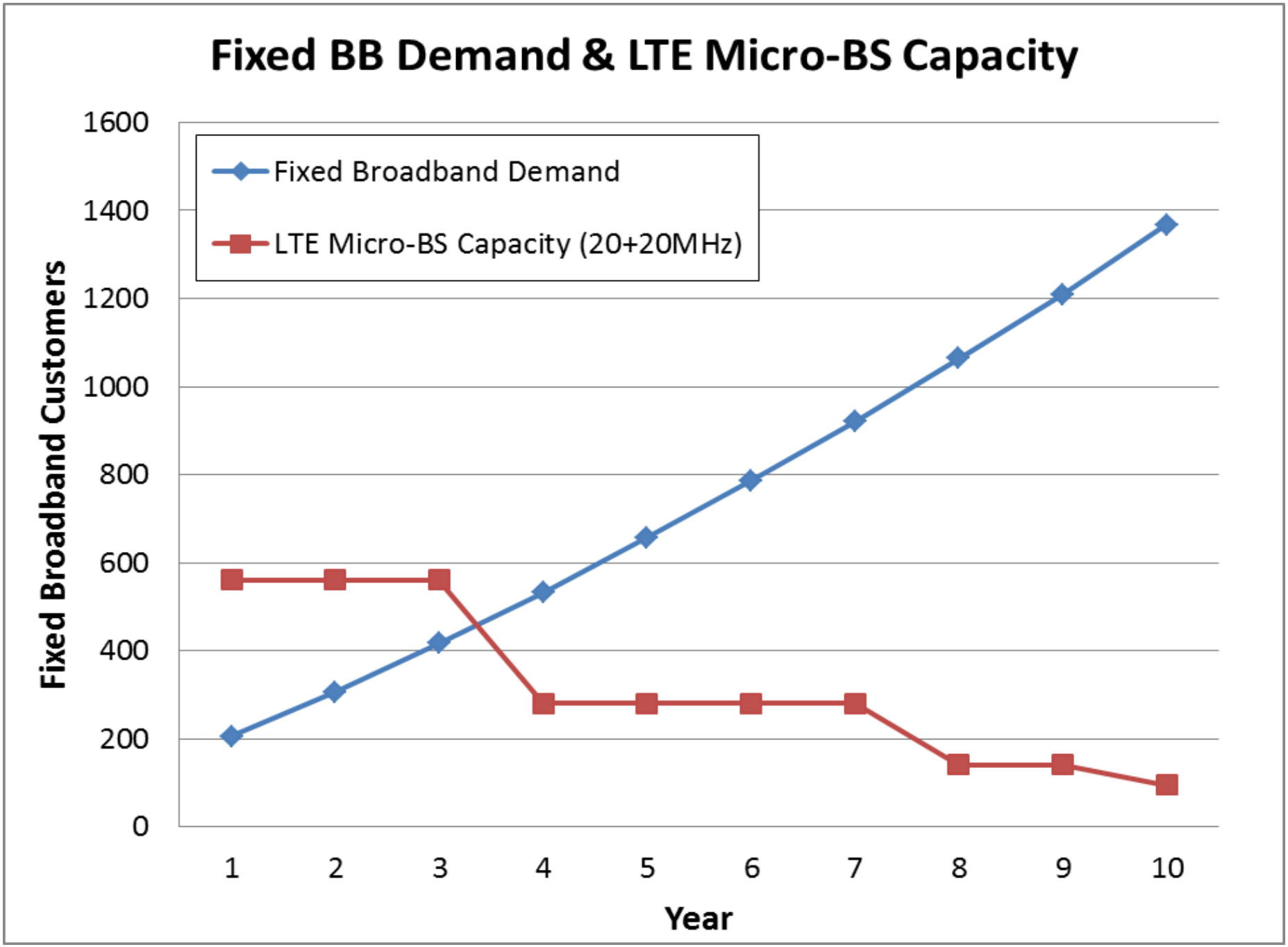
Yauli Area

(Andes Region)

LTE Technology

- Year 10
- 12Mbps




Fixed BB Demand & LTE Micro-BS Capacity
Fixed Broadband Demand
LTE Micro-BS Capacity (20+20MHz)
Fixed Broadband Customers
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
Year

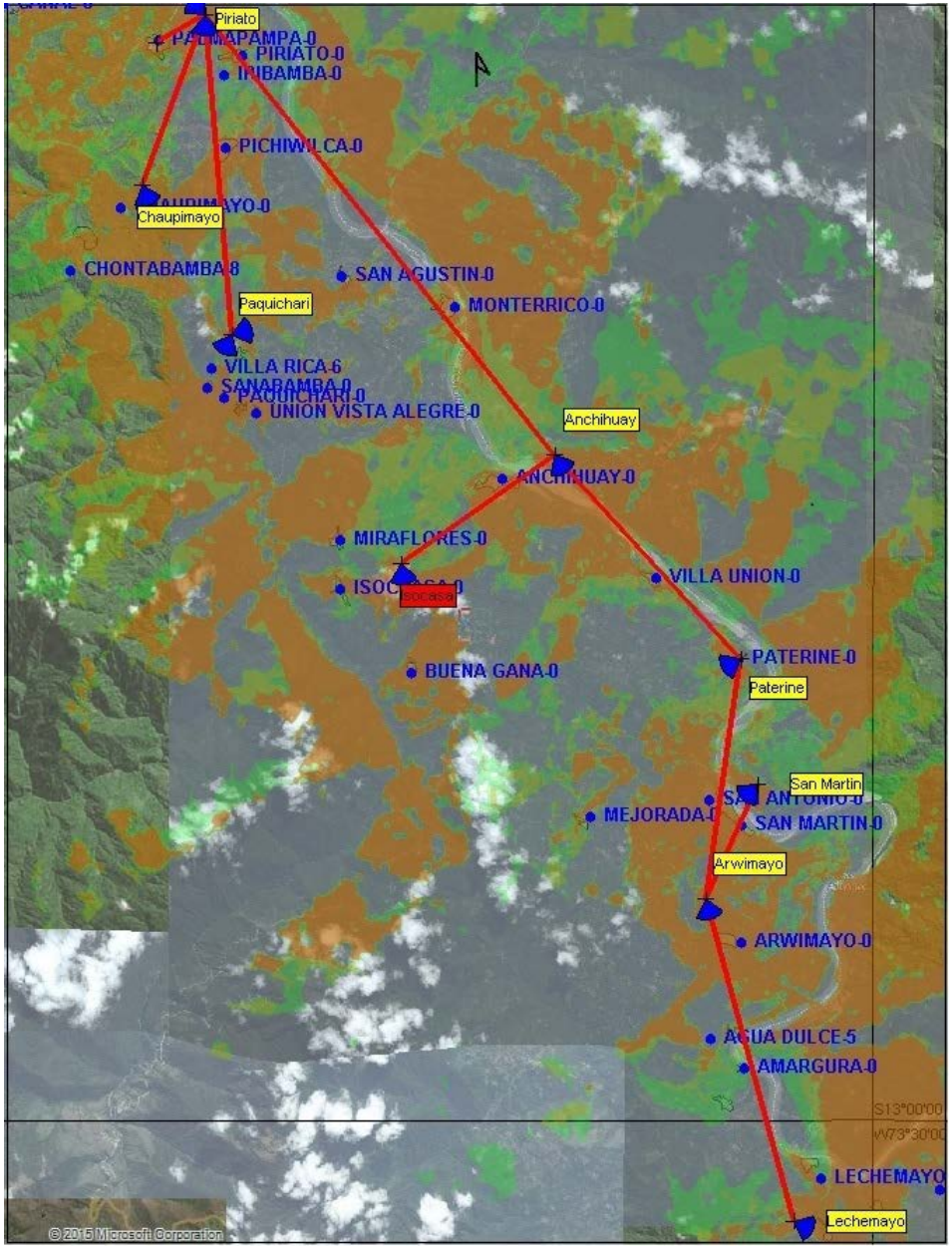
		Wi-Fi	WiMAX	TVWS	LTE	Balloons
Y1 2Mbps	Nodes and Towers	9	4	2	4	1
	Base Stations/Access Points	12	4	5	4	1
	Backhaul Radio Links	8	3	1	3	1
	Customer Premise Equipment	205	205	205	205	205
Y4 4Mbps	Nodes and Towers	9	5	5	5	
	Base Stations/Access Points	12	9	23	7	
	Backhaul Radio Links	8	4	4	4	
	Customer Premise Equipment	532	532	532	532	
Y8 8Mbps	Nodes and Towers	11	8	8	12	
	Base Stations/Access Points	26	28	85	23	
	Backhaul Radio Links	12	10	9	14	
	Customer Premise Equipment	1064	1064	1064	1064	
Y10 12Mbps	Nodes and Towers	18	12	12	16	
	Base Stations/Access Points	46	50	158	31	
	Backhaul Radio Links	23	19	18	23	
	Customer Premise Equipment	1368	1368	1368	1368	

Samugari Area

(Amazon Region)

LTE Technology

- Year 1 to Year 7
- 2Mbps and 4Mbps

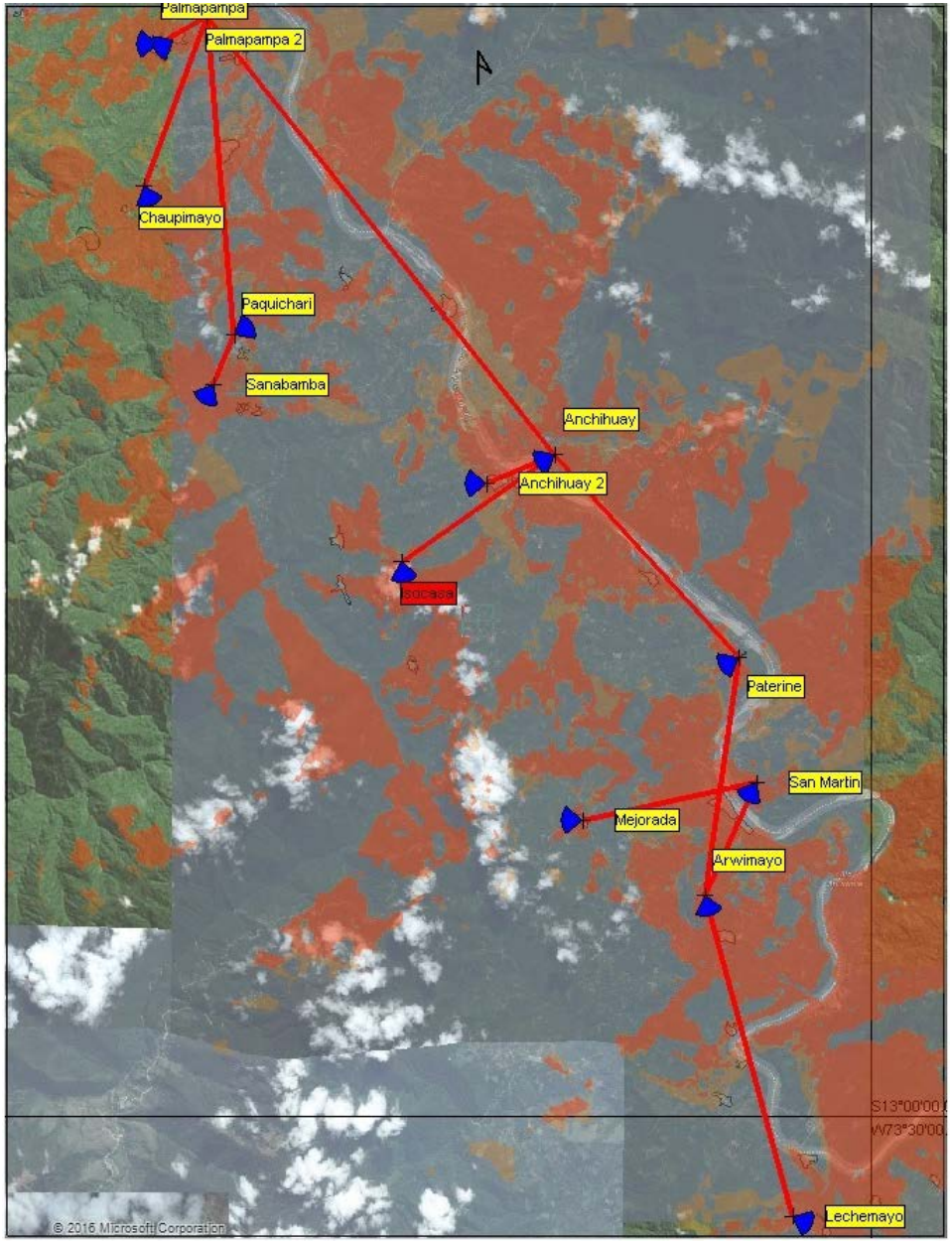


Samugari Area

(Amazon Region)

LTE Technology

- Year 8 to Year 9
- 8Mbps

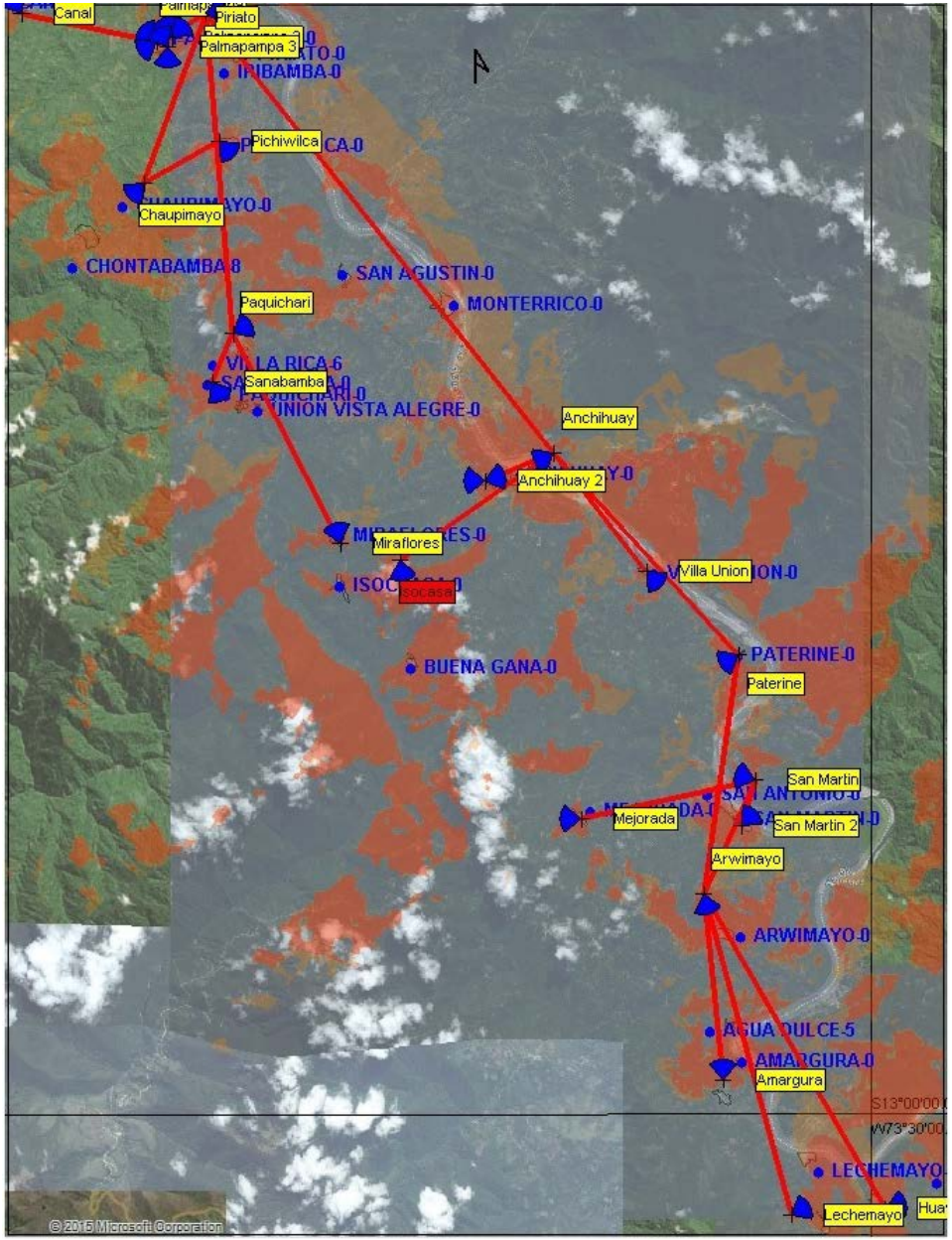


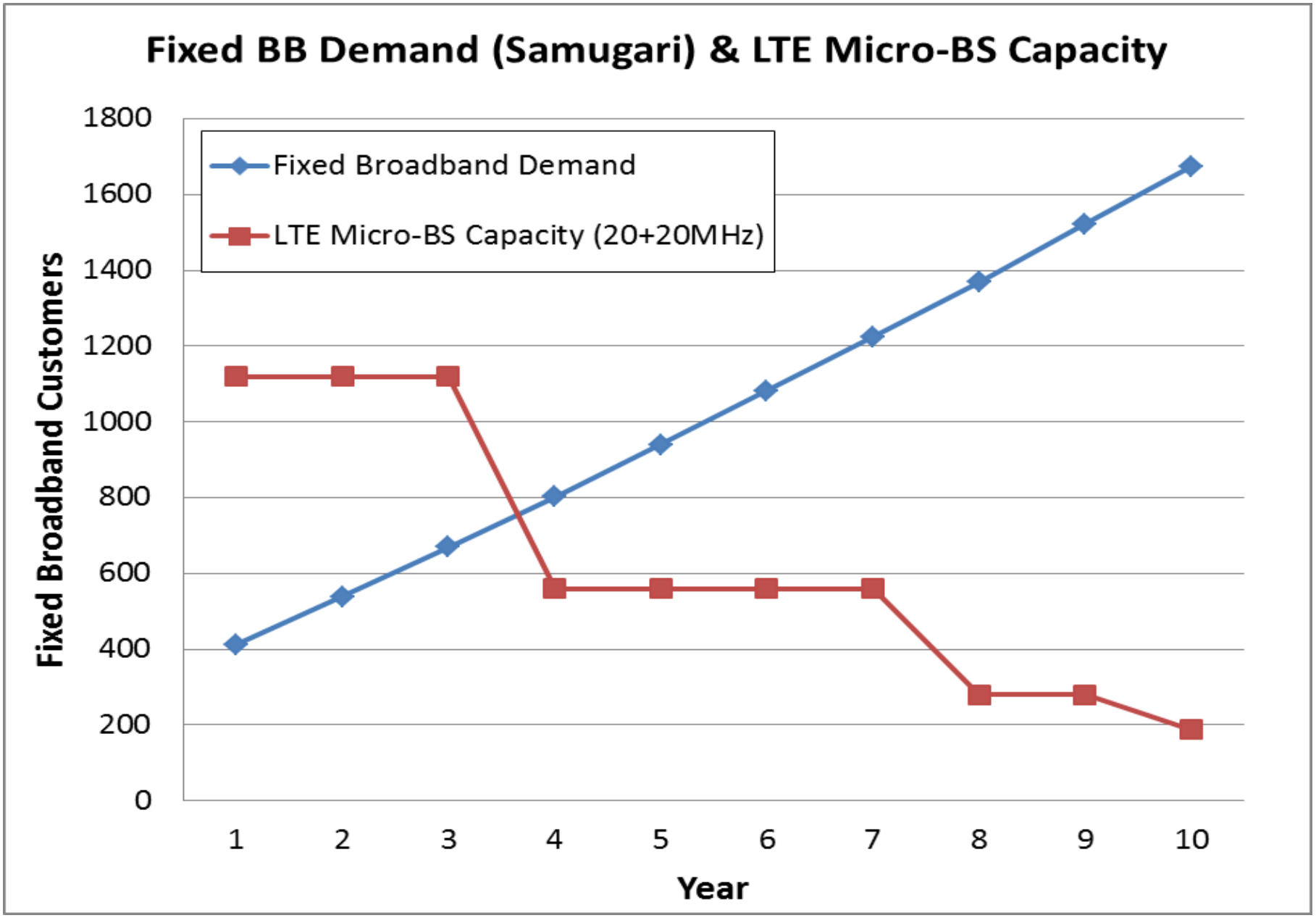
Samugari Area

(Amazon Region)

LTE Technology

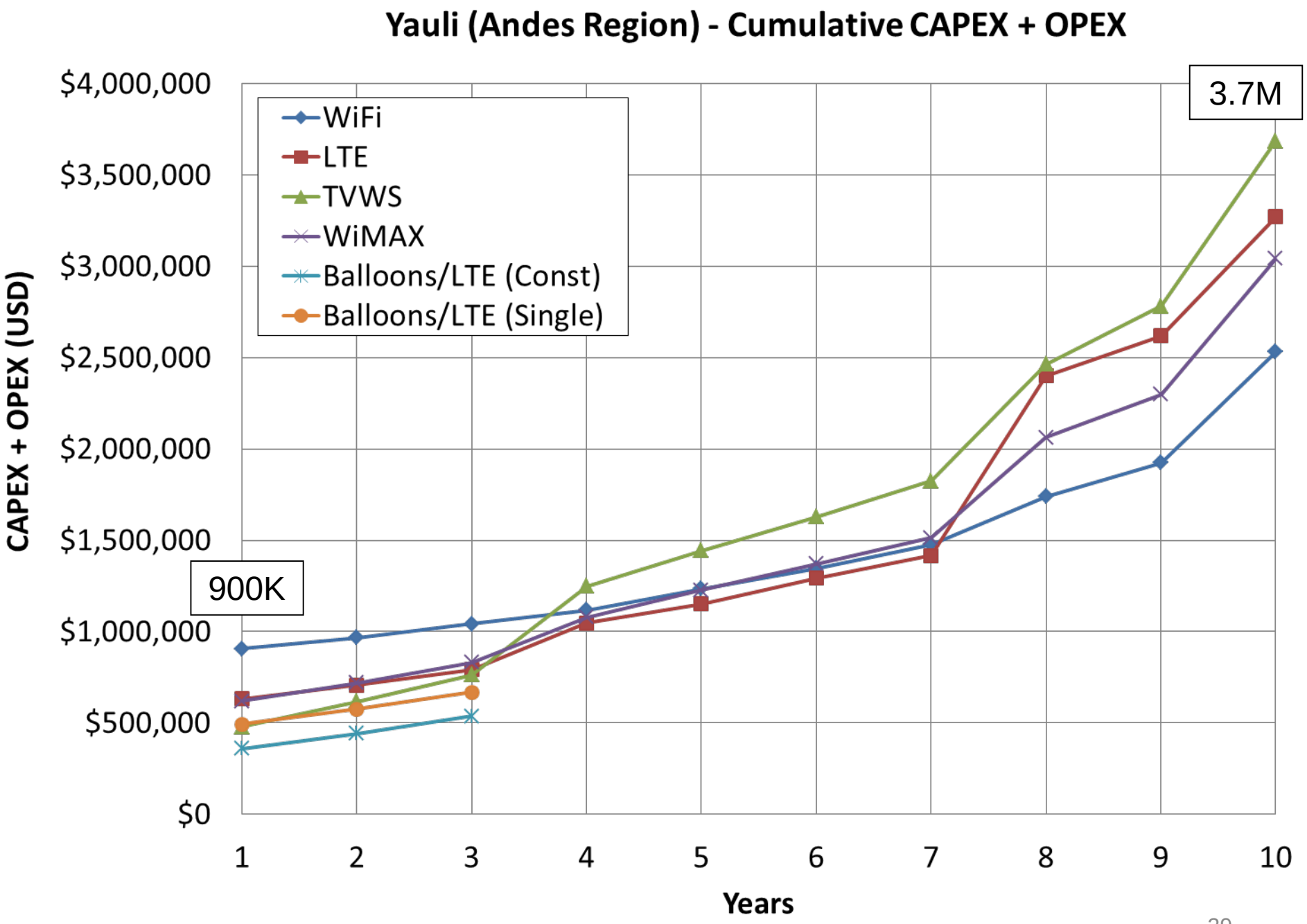
- Year 10
- 12Mbps

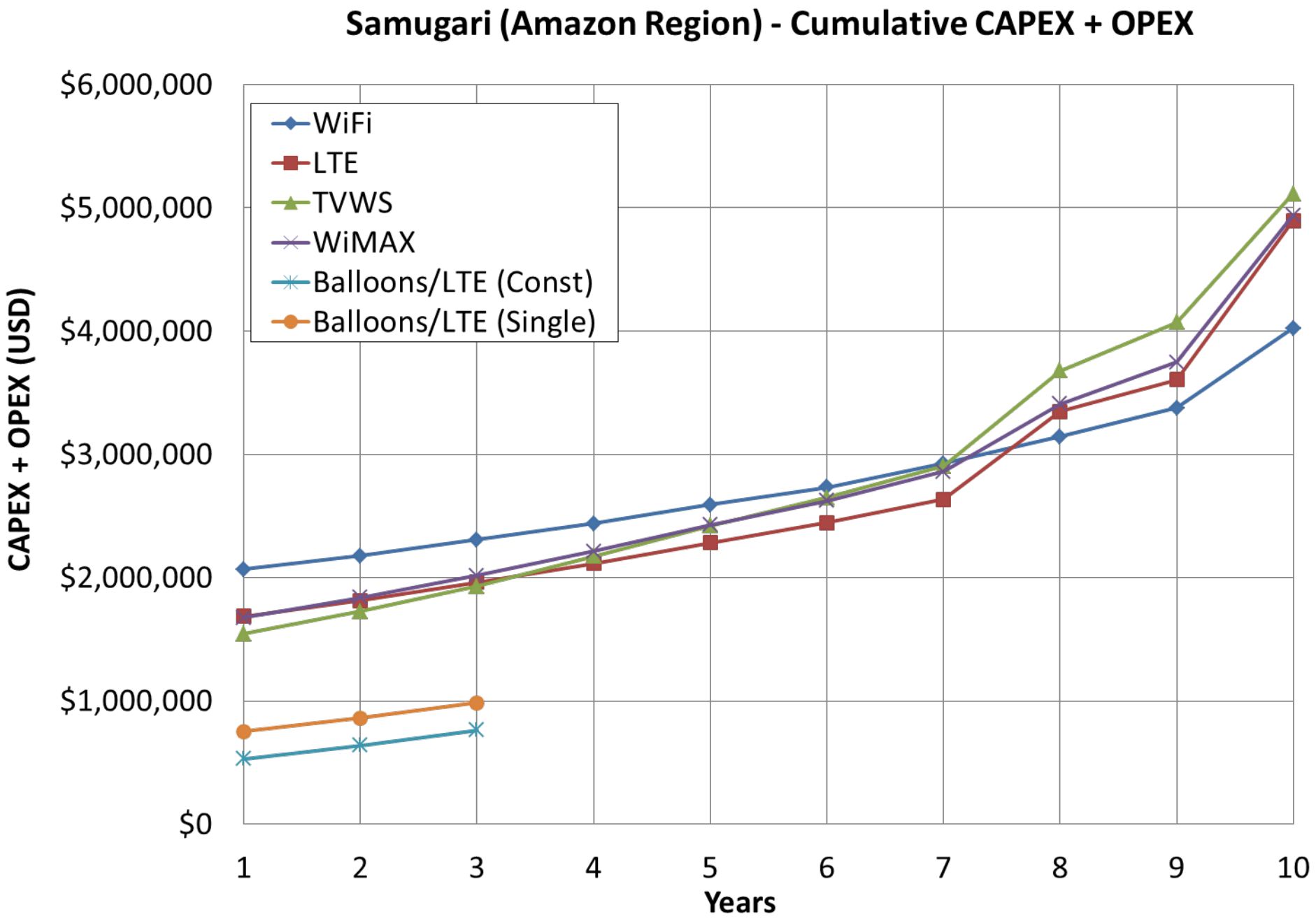



Fixed BB Demand (Samugari) & LTE Micro-BS Capacity
Fixed Broadband Demand
LTE Micro-BS Capacity (20+20MHz)
Fixed Broadband Customers
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
Year

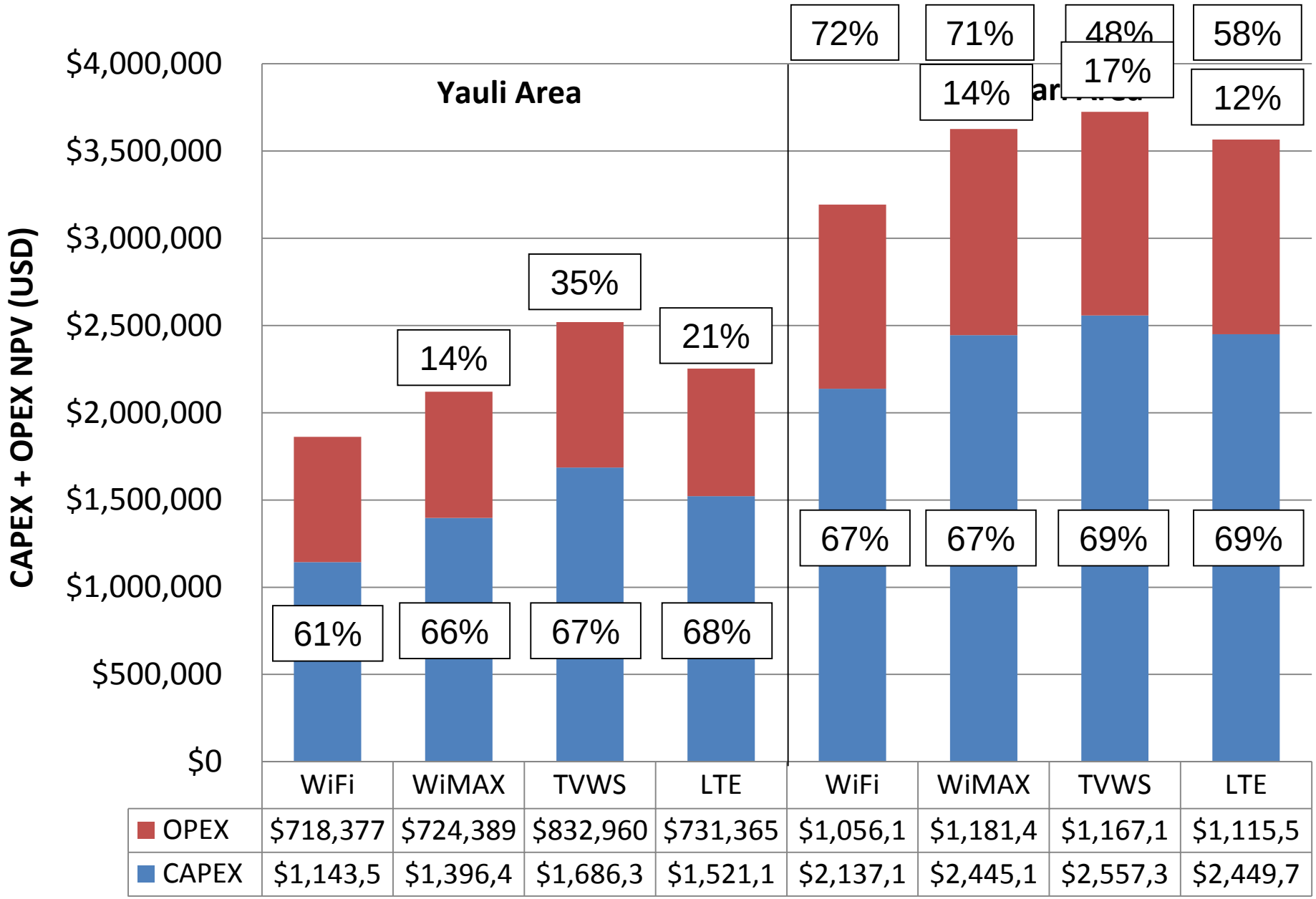
		Wi-Fi	WiMAX	TVWS	LTE	Balloons
Y1 2Mbps	Nodes and Towers	18	10	9	10	1
	Base Stations/Access Points	18	14	13	11	1
	Backhaul Radio Links	17	9	8	9	1
	Customer Premise Equipment	413	413	413	413	413
Y4 4Mbps	Nodes and Towers	18	10	9	10	
	Base Stations/Access Points	18	15	32	11	
	Backhaul Radio Links	18	10	9	10	
	Customer Premise Equipment	803	803	803	803	
Y8 8Mbps	Nodes and Towers	18	12	12	14	
	Base Stations/Access Points	27	34	111	18	
	Backhaul Radio Links	25	19	19	21	
	Customer Premise Equipment	1368	1368	1368	1368	
Y10 12Mbps	Nodes and Towers	22	18	17	22	
	Base Stations/Access Points	46	62	170	27	
	Backhaul Radio Links	38	34	33	38	
	Customer Premise Equipment	1675	1675	1675	1675	

4. Engineering Cost Analysis Results


Yauli (Andes Region) - Cumulative CAPEX + OPEX
$4,000,000
$3,500,000
$3,000,000
$2,500,000
$2,000,000
$1,500,000
$1,000,000
$500,000
$0
CAPEX + OPEX (USD)
WiFi
LTE
TVWS
WiMAX
Balloons/LTE (Const)
Balloons/LTE (Single)
3.7M
900K
1
2
3
4
5
6
7
8
9
10
Years

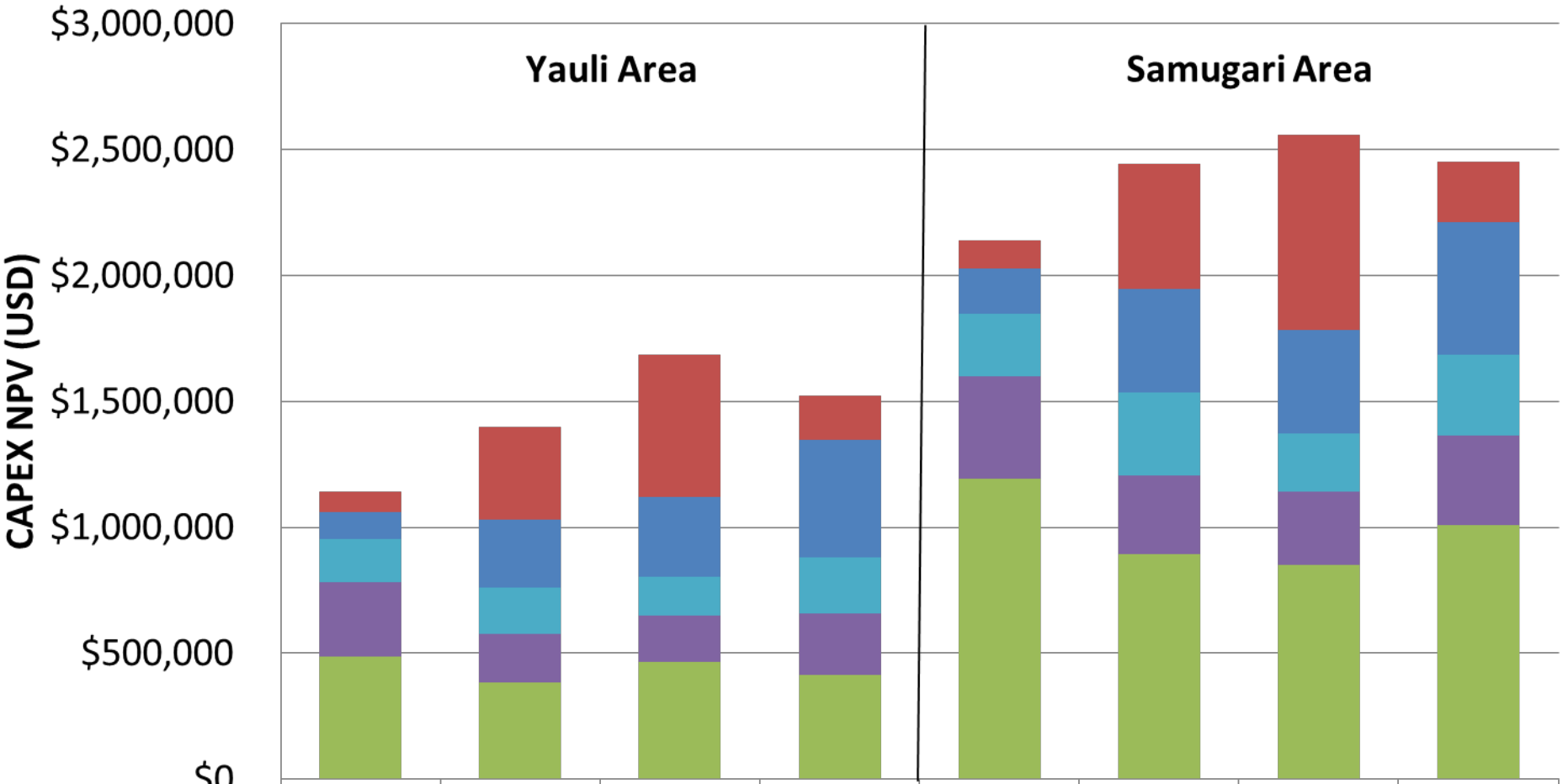

Samugari (Amazon Region) - Cumulative CAPEX + OPEX
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
CAPEX + OPEX (USD)
WiFi
LTE
TVWS
WiMAX
Balloons/LTE (Const)
Balloons/LTE (Single)
1
2
3
4
5
6
7
8
9
10
Years

Yauli (Andes Region) & Samugari (Amazon Region) CAPEX+OPEX NPV



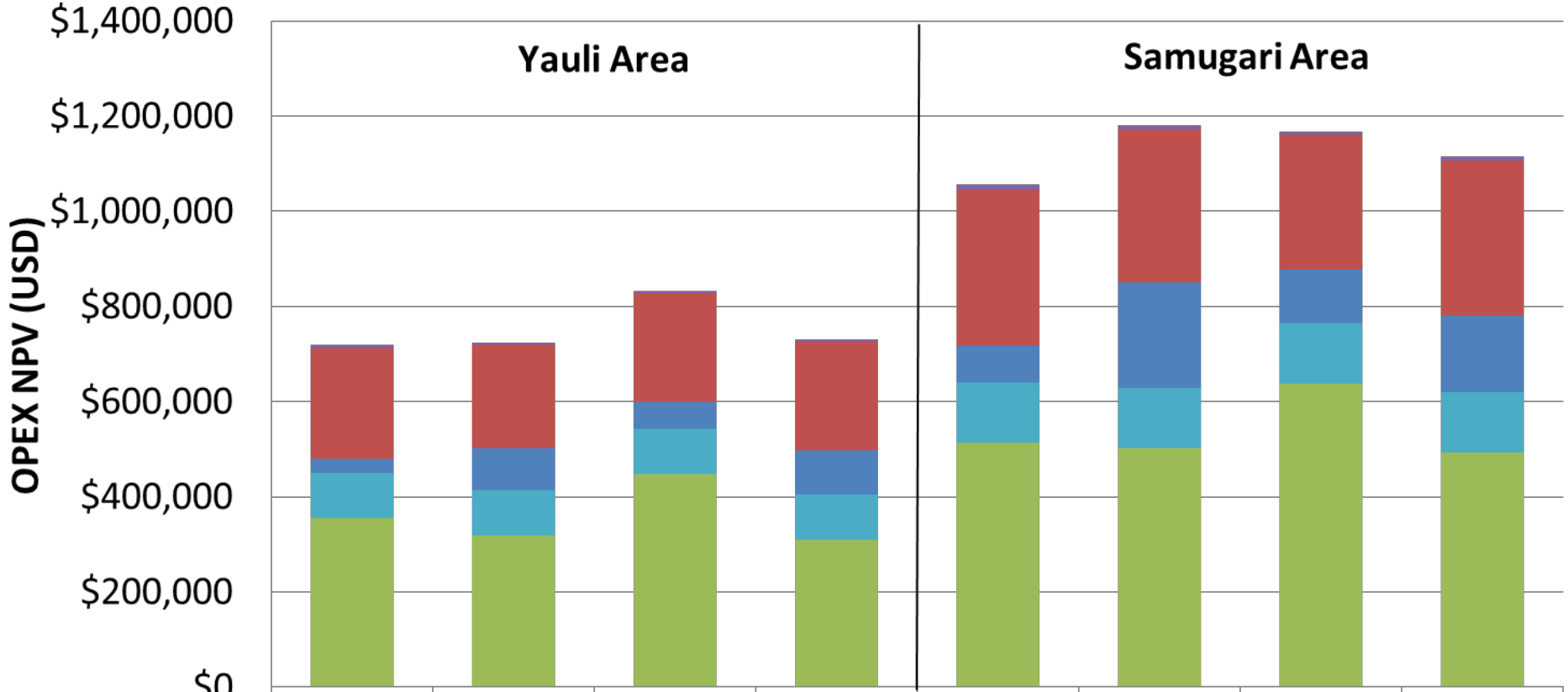
	WiFi	WiMAX	TVWS	LTE	WiFi	WiMAX	TVWS	LTE
OPEX	$718,377	$724,389	$832,960	$731,365	$1,056,1	$1,181,4	$1,167,1	$1,115,5
CAPEX	$1,143,5	$1,396,4	$1,686,3	$1,521,1	$2,137,1	$2,445,1	$2,557,3	$2,449,7

Yauli (Andes Region) - Samugari (Amazon Region) - CAPEX NPV



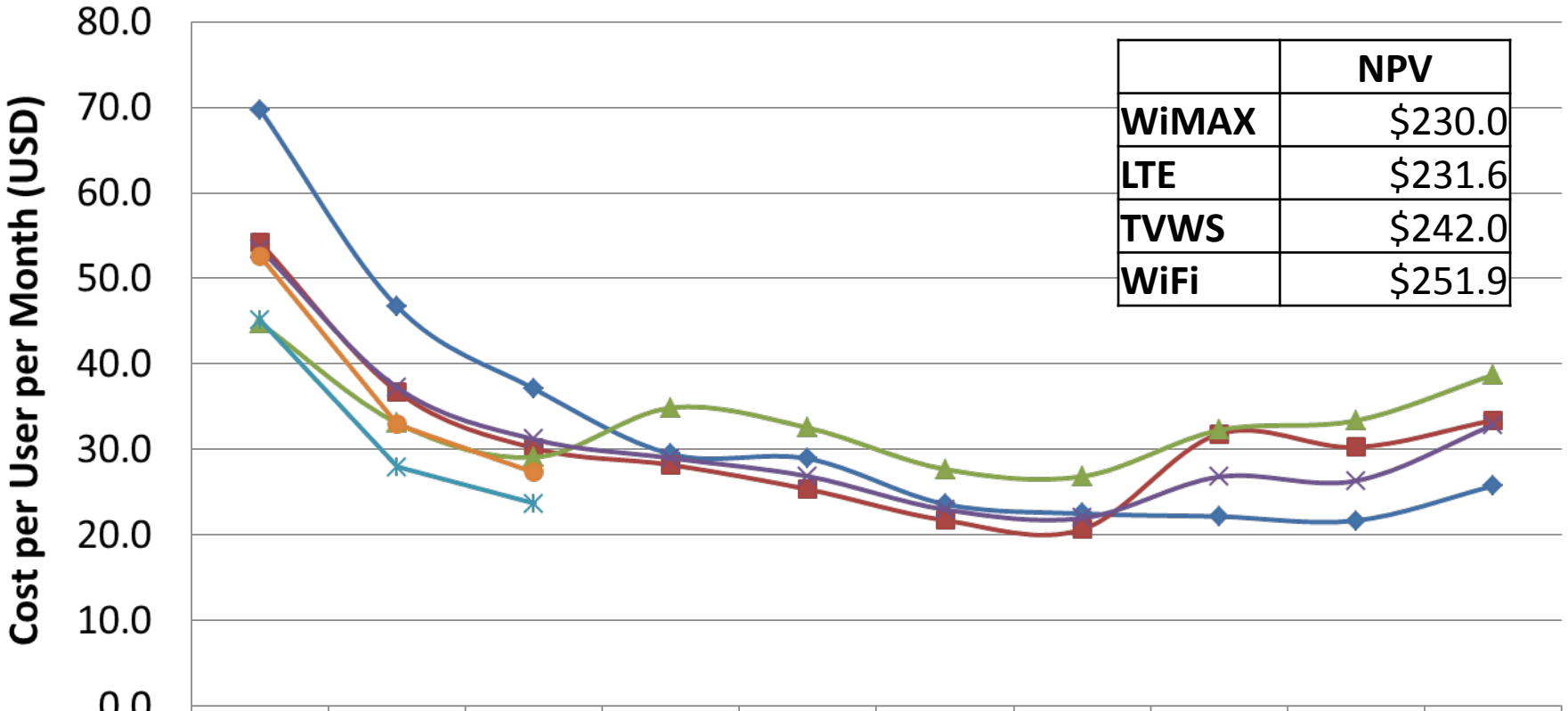
	WiFi	WiMAX	TVWS	LTE	WiFi	WiMAX	TVWS	LTE
CPE	$83,651	$364,187	$567,493	$175,860	$111,301	$496,557	$775,366	$236,828
Network	$108,065	$269,565	$314,822	$464,586	$178,321	$411,111	$409,668	$525,783
Energy	$170,017	$186,245	$154,237	$224,309	$246,345	$331,560	$229,486	$323,905
Civil Eng.	$295,393	$190,968	$184,412	$242,641	$408,811	$312,226	$291,330	$354,209
Towers	$486,452	$385,481	$465,381	$413,783	$1,192,3	$893,656	$851,537	$1,009,0

Yauli (Andes Region) - Samugari (Amazon Region) - OPEX NPV



	WiFi	WiMAX	TVWS	LTE	WiFi	WiMAX	TVWS	LTE
Operation Fees	$6,215	$5,395	$5,395	$6,215	$10,418	$10,045	$6,215	$10,418
HQ operations	$232,332	$216,031	$228,377	$226,823	$328,498	$321,005	$282,942	$325,916
Electricity	$29,603	$88,865	$56,093	$93,596	$77,437	$221,861	$114,160	$160,116
F.O. Intercon.	$95,881	$95,881	$95,881	$95,881	$126,652	$126,652	$126,652	$126,652
Personnel	$354,345	$318,217	$447,214	$308,850	$513,161	$501,863	$637,211	$492,496

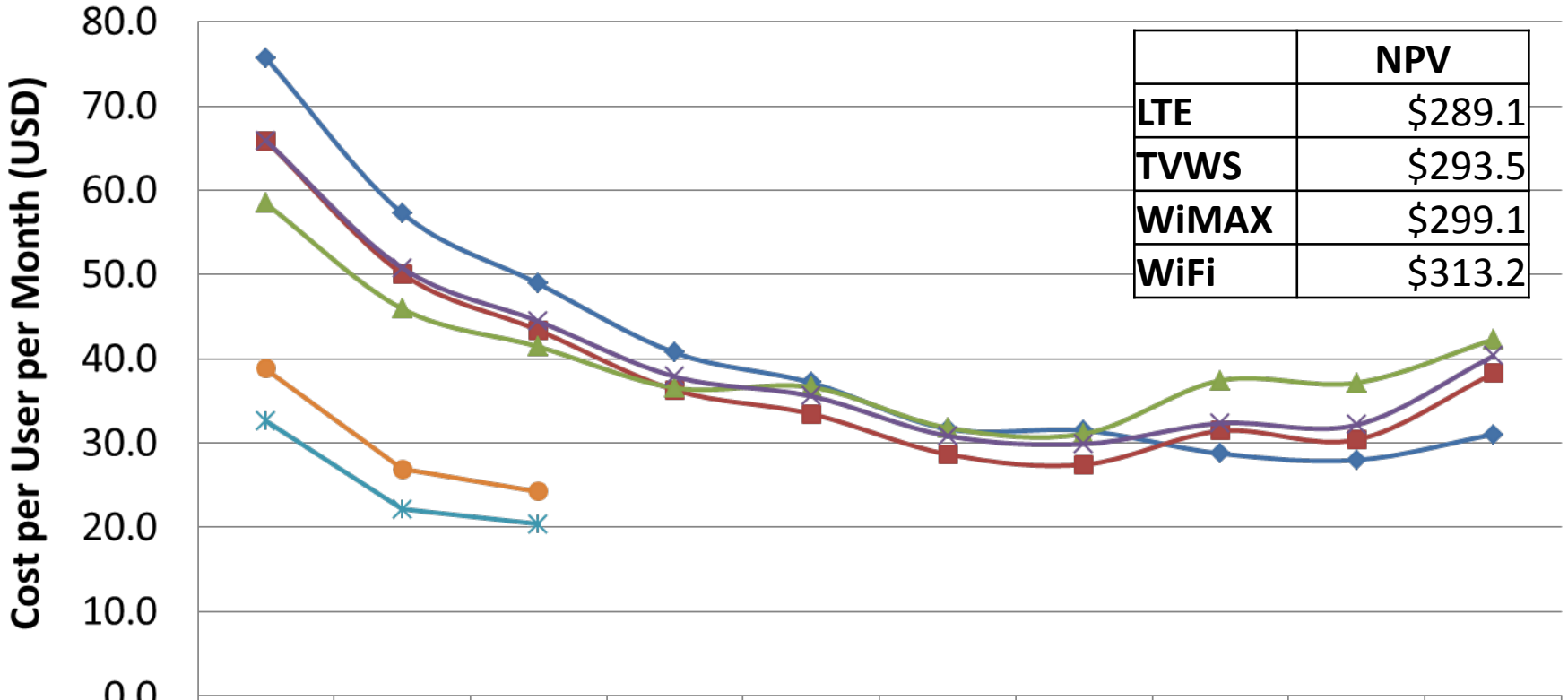
Yauli (Andes Region) - Cost per User per Month



	NPV
WiMAX	$230.0
LTE	$231.6
TVWS	$242.0
WiFi	$251.9

	1	2	3	4	5	6	7	8	9	10
WiFi	69.7	46.7	37.1	29.5	28.9	23.6	22.5	22.2	21.7	25.7
LTE	54.2	36.8	30.2	28.2	25.4	21.7	20.7	31.8	30.3	33.4
TVWS	44.8	33.1	29.1	34.9	32.5	27.7	26.9	32.3	33.4	38.7
WiMAX	53.4	37.2	31.2	29.0	26.9	23.0	22.0	26.8	26.3	32.8
Balloons-C	45.1	28.0	23.7							
Balloons-S	52.6	33.0	27.4							

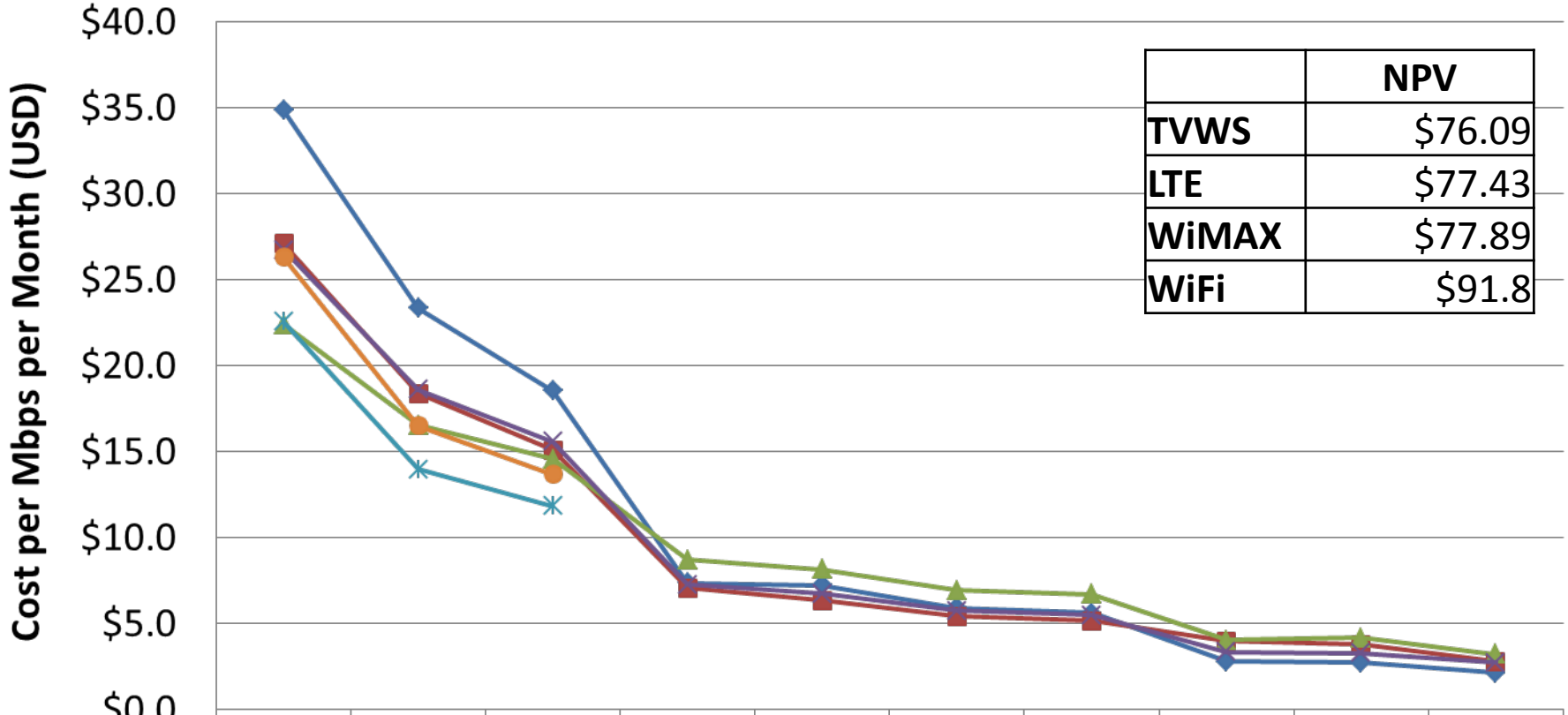
Samugari (Amazon Region) - Cost per User per Month



	NPV
LTE	$289.1
TVWS	$293.5
WiMAX	$299.1
WiFi	$313.2

	1	2	3	4	5	6	7	8	9	10
WiFi	75.7	57.3	48.9	40.7	37.2	31.7	31.5	28.8	28.0	31.0
LTE	65.9	50.1	43.4	36.3	33.5	28.7	27.4	31.4	30.4	38.3
TVWS	58.4	45.9	41.4	36.5	36.6	31.8	31.1	37.4	37.1	42.3
WiMAX	65.9	50.8	44.4	37.9	35.6	30.8	29.9	32.4	32.2	40.3
Balloons-C	32.6	22.1	20.4							
Balloons-S	38.8	26.9	24.2							

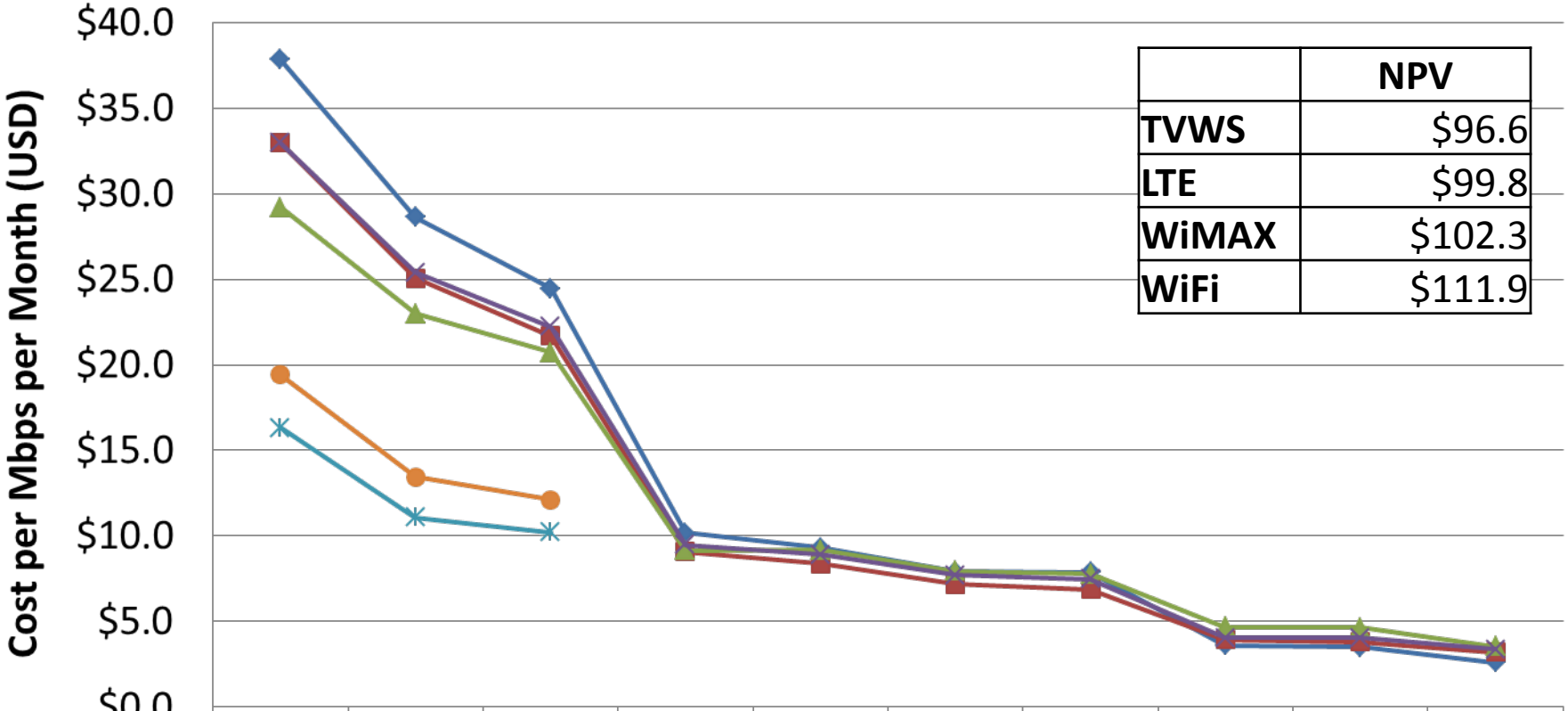
Yauli (Andes Region) - Cost per Mbps per Month



	NPV
TVWS	$76.09
LTE	$77.43
WiMAX	$77.89
WiFi	$91.8

	1	2	3	4	5	6	7	8	9	10
WiFi	$34.8	$23.3	$18.5	$7.4	$7.2	$5.9	$5.6	$2.8	$2.7	$2.1
LTE	$27.1	$18.4	$15.1	$7.1	$6.3	$5.4	$5.2	$4.0	$3.8	$2.8
TVWS	$22.4	$16.5	$14.6	$8.7	$8.1	$6.9	$6.7	$4.0	$4.2	$3.2
WiMAX	$26.7	$18.6	$15.6	$7.2	$6.7	$5.7	$5.5	$3.4	$3.3	$2.7
Balloons-C	$22.5	$14.0	$11.8							
Balloons-S	$26.3	$16.5	$13.7							

Samugari (Amazon Region) - Cost per Mbps per Month



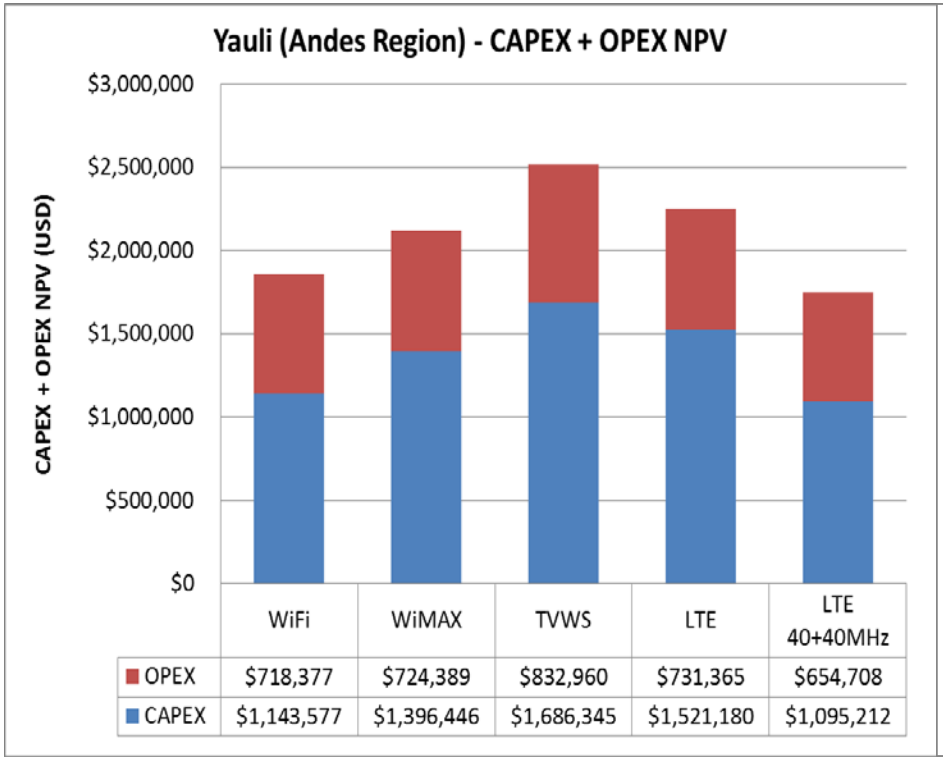
	NPV
TVWS	$96.6
LTE	$99.8
WiMAX	$102.3
WiFi	$111.9

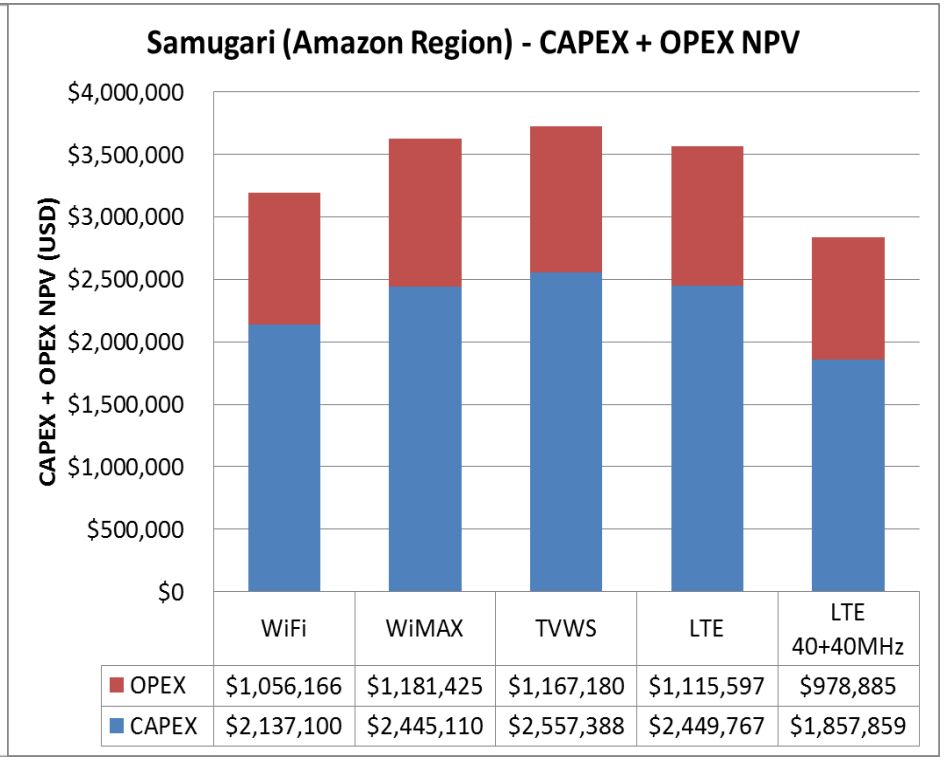
	1	2	3	4	5	6	7	8	9	10
WiFi	$37.8	$28.6	$24.5	$10.2	$9.3	$7.9	$7.9	$3.6	$3.5	$2.6
LTE	$32.9	$25.0	$21.7	$9.1	$8.4	$7.2	$6.9	$3.9	$3.8	$3.2
TVWS	$29.2	$23.0	$20.7	$9.1	$9.2	$8.0	$7.8	$4.7	$4.6	$3.5
WiMAX	$33.0	$25.4	$22.2	$9.5	$8.9	$7.7	$7.5	$4.0	$4.0	$3.4
Balloons-C	$16.3	$11.1	$10.2							
Balloons-S	$19.4	$13.4	$12.1							

5. Policy Implications & Broadband Technology Roadmap

Policy Implications – LTE Spectrum

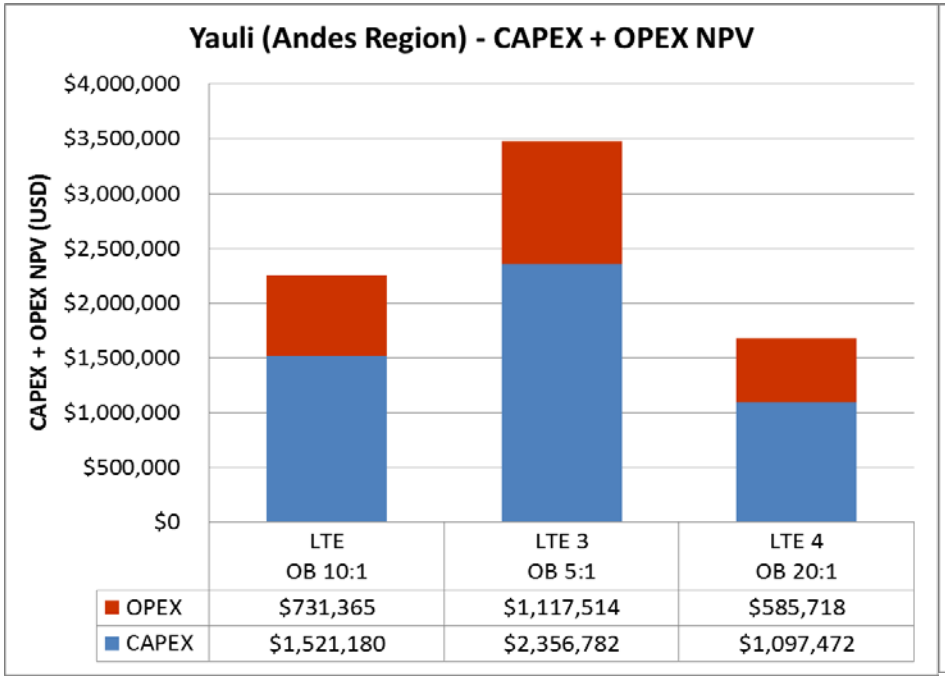
- 1.7/2.1GHz Band (AWS) LTE spectrum cap: 20MHz+20MHz
- Allowing 40MHz+40MHz spectrum per operator:
  - Less expensive than Wi-Fi (NPV reduction 6% in Yauli and 11% In Samugari)
  - Less expensive than LTE (NPV reduction 22% in Yauli and 20% In Samugari)

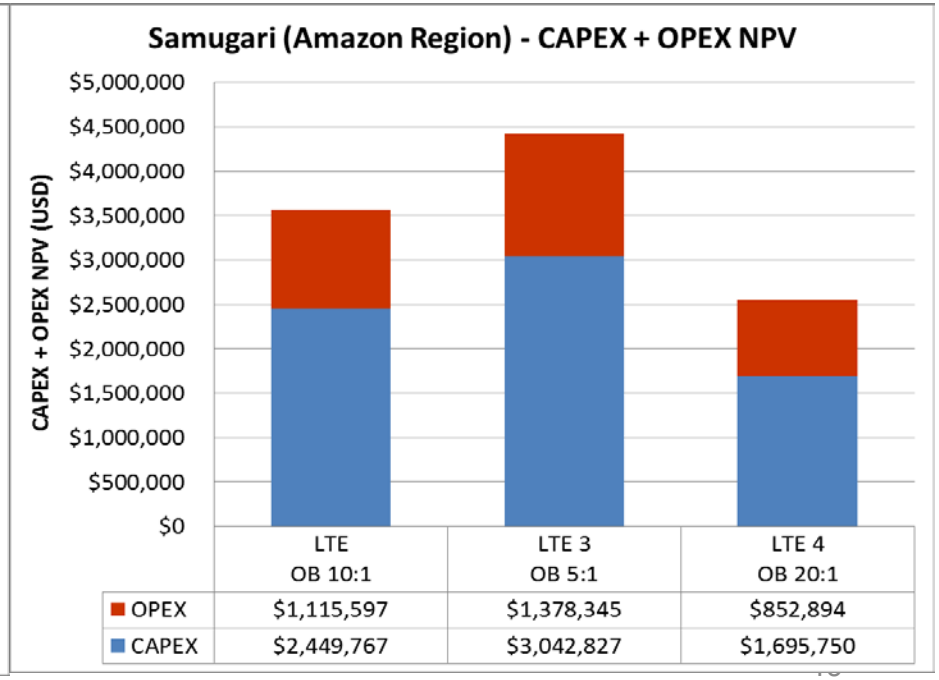




Overbooking Analysis

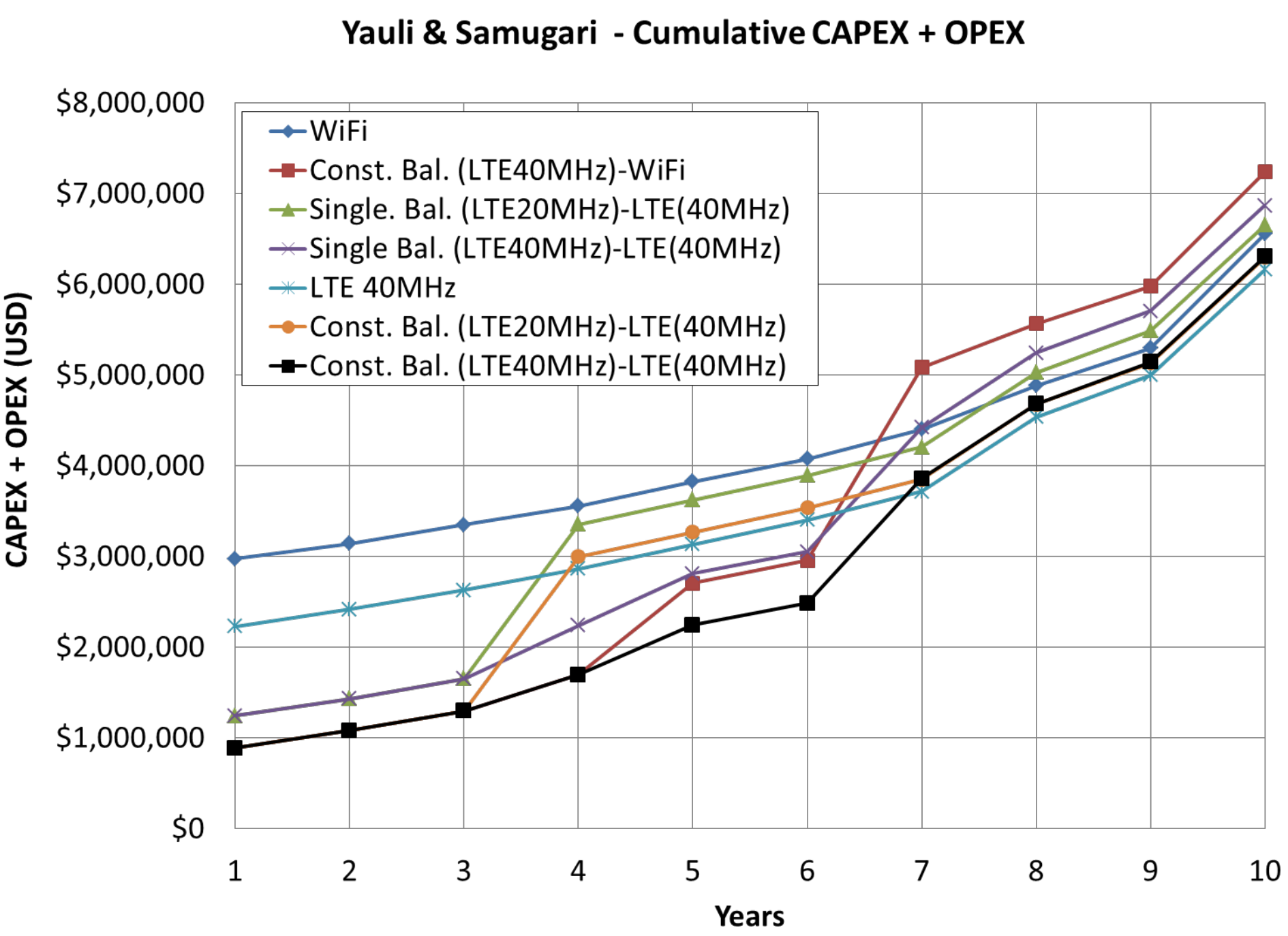
- Current regulator recommendation for residential service in rural areas is an overbooking of 10:1.
- Variations in the overbooking in rural areas have significant impact on cost:
  - Overbooking 5:1 (LTE NPV increase 54% in Yauli and 24% In Samugari)
  - Overbooking 20:1 (LTE NPV decrease 25% in Yauli and 29% In Samugari)



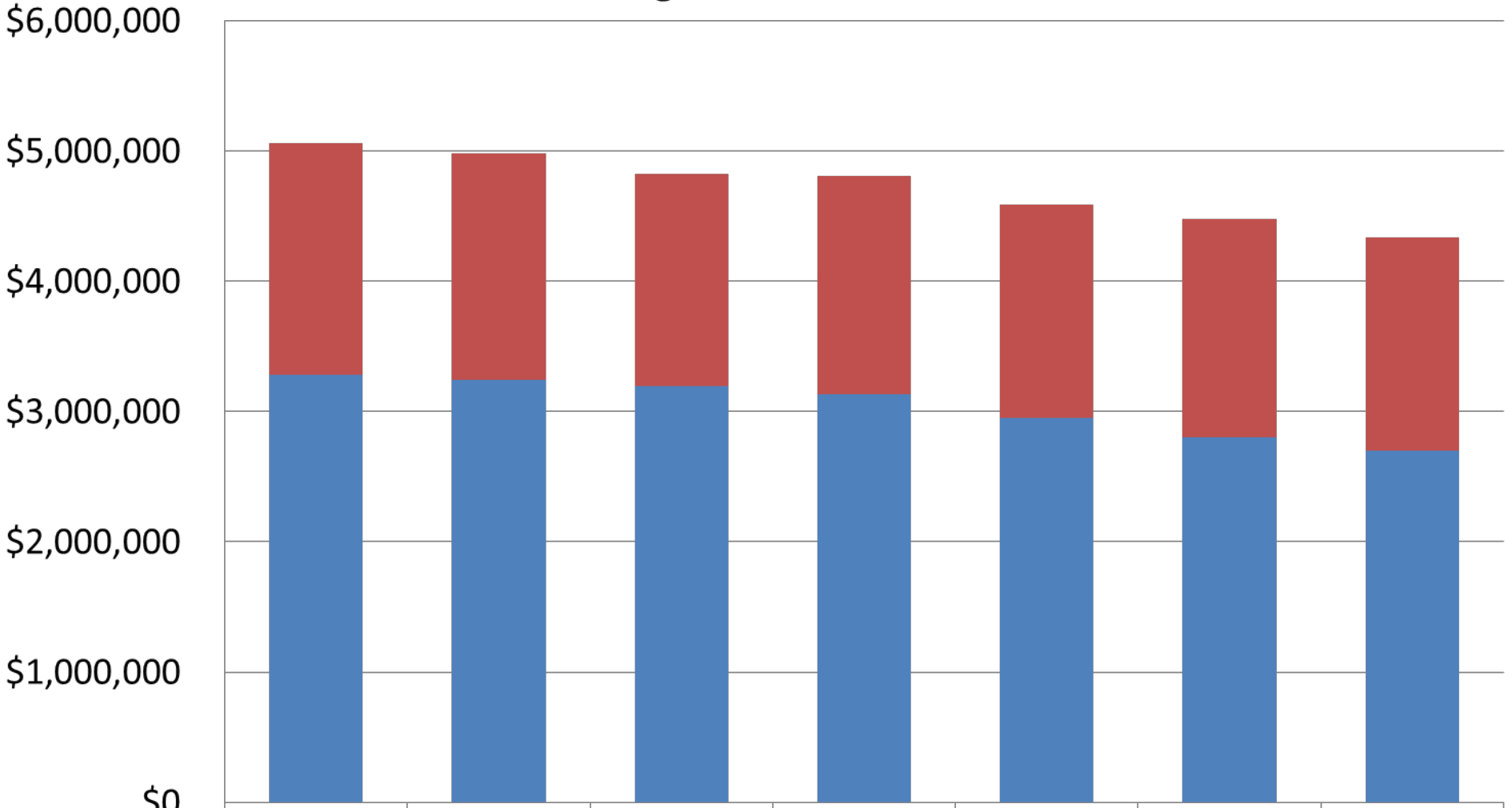


Broadband Technology Roadmap

- **1st Step:** Use technical and engineering cost analyses results of current wireless technologies and new stratospheric platforms.
  - Stratospheric balloons have lowest cost for first 3 years.
  - WiFi has the lowest cost among current wireless options.
  - LTE 40+40MHz has lower costs than WiFi.
- **2nd Step:** Combine best technical features and cost efficiencies into an innovative roadmap solution.
  - Use stratospheric balloons for first few years.
  - Complementary Wi-Fi or LTE 40MHz terrestrial networks .


Yauli & Samugari - Cumulative CAPEX + OPEX
$8,000,000
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
CAPEX + OPEX (USD)
1
2
3
4
5
6
7
8
9
10
Years
WiFi
Const. Bal. (LTE40MHz)-WiFi
Single. Bal. (LTE20MHz)-LTE(40MHz)
Single Bal. (LTE40MHz)-LTE(40MHz)
LTE 40MHz
Const. Bal. (LTE20MHz)-LTE(40MHz)
Const. Bal. (LTE40MHz)-LTE(40MHz)

Yauli & Samugari - CAPEX + OPEX NPV



	WiFi	Const. Bal. (LTE40MHz) -WiFi	Single Bal. (LTE40MHz)- LTE40MHz	Single. Bal. (LTE20MHz) -LTE(40MHz)	LTE 40MHz	Const. Bal. (LTE20MHz)- LTE(40MHz)	Const. Bal. (LTE40MHz)- LTE(40MHz)
OPEX	$1,774,543	$1,740,548	$1,633,918	$1,675,581	$1,633,593	$1,675,369	$1,633,587
CAPEX	$3,280,676	$3,239,505	$3,192,506	$3,134,788	$2,953,071	$2,801,812	$2,698,174

Broadband Technology Roadmap

The two selected roadmap solutions:

- Stratospheric constellation balloons (LTE 20MHz) complemented with terrestrial LTE 40MHz.
- Stratospheric constellation balloons (LTE 40MHz) complemented with terrestrial LTE 40MHz.

6. Conclusions

Research Hypotheses

- **Hypothesis 1**

  *Deploying wireless access networks in the Andes and Amazon regions of Peru using the **Wi-Fi technology** and unlicensed spectrum has the **lowest deployment and operating cost** in a **10-year period**.*

  – This hypothesis is true
    – Andes Region (Yauli): Lowest NPV (WiMAX, LTE and TVWS are 14%, 21% and 35% more expensive).
    – Amazon Region (Samugari): Lowest NPV (LTE, WiMAX and TVWS are 12%, 14% and 17% more expensive).

Research Hypotheses

- **Hypothesis 2**

  *Wireless access networks using **stratospheric platforms** in the Andes and Amazon regions of Peru has the **lowest deployment and operating cost** for the **initial years** but are **not able to scale** for a **10-year period** to serve forecasted customer and speed growth.*

  – This hypothesis is true

    – Under current spectrum regulations, balloons can provide service for first 3 years at the lowest cost.

    – Allowing LTE 40+40MHz, balloons can provide service for 4 years in Yauli and for 6 years in Samugari.

Research Hypotheses

- **Hypothesis 3**

  Spectrum management and regulation *have a quantifiable* ***technology and economic impact*** *in the deployment and operation of wireless access networks in the Andes and Amazon regions of Peru and are important to define the* ***best technology fit*** *to introduce broadband services in these regions.*

  – This hypothesis is true
    – Spectrum regulations have an impact on the available spectrum resources used in the technical analysis.
    – Technical design has a direct impact of the network costs.
    – Lifting the LTE spectrum cap allows LTE to become the lowest cost option.

Research Question

- **Research Question**

  "What is the technology roadmap for introducing broadband services to underserved and unserved areas in the Andes and Amazon Regions of Peru?"

  – The two broadband roadmap selected solutions:

    - Stratospheric constellation balloons (LTE 20MHz) complemented with terrestrial LTE 40MHz.
    - Stratospheric constellation balloons (LTE 40MHz) complemented with terrestrial LTE 40MHz.

Acknowledgements

- Dr. David Reed
- Dissertation committee
- Dr. Harvey Gates
- FITEL
- Google and ITP
- My wife Sarah, family and friends

Thank you!

Q & A

Subsidy Analysis

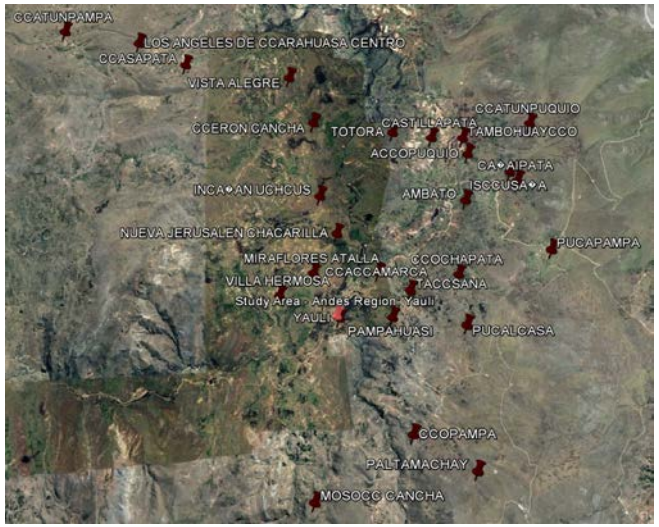
	Cost per user per month in Yauli (USD)	**Subsidy per user per month in Huancavelica (USD)**
Wi-Fi	$ 31.6	$ 44.3
WiMAX	$ 36.0	$ 44.3
TVWS	$ 42.8	$ 44.3
LTE	$ 38.2	$ 44.3

	Cost per user per month in Samugari (USD)	**Subsidy per user per month in Ayacucho (USD)**
Wi-Fi	$ 38.8	$ 27.2
WiMAX	$ 44.0	$ 27.2
TVWS	$ 45.2	$ 27.2
LTE	$ 43.3	$ 27.2

Network Radio Links Summary

		YAULI				SAMUGARI			
		WiFi	WiMAX	TVWS	LTE	WiFi	WiMAX	TVWS	LTE
Average Distance from Towns to Nodes (km)	Year 1	1.3	3.6	4.4	3.5	0.8	2.4	3.4	2.2
	Year 4	1.3	1.8	2.3	1.8	0.8	2.4	3.4	2.2
	Year 8	1.0	1.3	1.3	1.1	0.8	1.9	1.7	1.9
	Year 10	0.7	1.1	1.0	0.9	0.7	1.5	1.4	1.0
Average Number of Towns per Nodes	Year 1	3.0	9.0	13.5	9.0	1.6	3.2	4.1	3.2
	Year 4	3.0	5.4	5.4	5.4	1.6	3.2	4.1	3.2
	Year 8	2.5	3.4	3.4	2.2	1.6	2.4	2.2	2.1
	Year 10	1.5	2.2	2.2	1.7	1.4	1.5	1.7	1.3
Average Backhaul Radio Link Distances	Year 1	4.0	3.8	3.4	3.8	5.5	6.0	5.7	6.0
	Year 4	4.0	3.9	4.5	3.9	5.5	6.0	5.7	6.0
	Year 8	3.6	3.2	3.9	2.8	5.5	5.6	5.8	4.8
	Year 10	2.7	2.7	2.8	2.3	4.7	4.7	4.8	4.3

Yauli County (Andes)

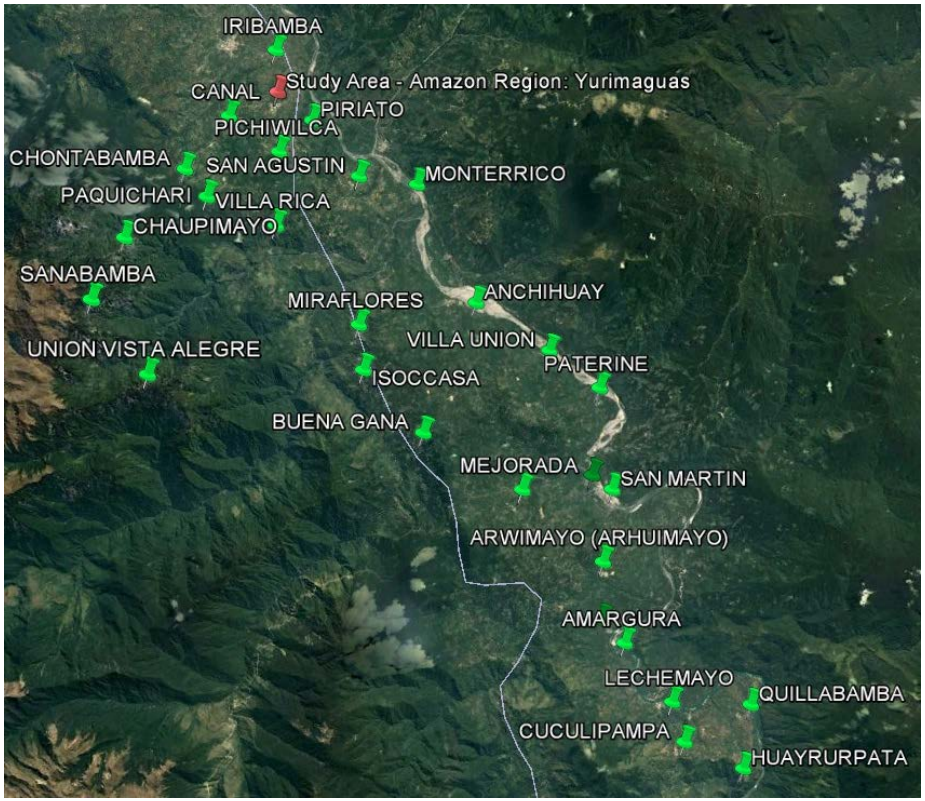


8 mi

8 mi

- 27 towns and 3,511 households
- Fixed BB demand: 4.7% of households (2.7% annual increase)
- Customers: 205 (Y1) to 1368 (Y10)

Samugari County (Amazon)



13 mi

- 29 towns and 3,884 households
- Fixed BB demand: 9.1% of households (2.9% annual increase)
- Customers: 413 (Y1) to 1675 (Y10)

Customer Demand - Yauli

	FITEL Towns Gov Customers	Additional Towns Gov Customers	Residential Penetration (%)	FITEL Towns Residential Customers	Additional Towns Residential Customers	Total Demand
Y=1 2015	34	14	4.7%	108	49	**205**
Y=2 2016	34	14	7.4%	182	76	**306**
Y=3 2017	34	14	10.1%	266	103	**417**
Y=4 2018	34	14	12.8%	350	134	**532**
Y=5 2019	34	14	15.5%	441	168	**657**
Y=6 2020	34	14	18.2%	536	202	**786**
Y=7 2021	34	14	20.9%	636	236	**920**
Y=8 2022	34	14	23.6%	741	275	**1064**
Y=9 2023	34	14	26.3%	849	312	**1209**
Y=10 2024	34	14	29%	964	356	**1368**

Customer Demand - Samugari

	FITEL Towns Gov Customers	Additional Towns Gov Customers	Residential Penetration (%)	FITEL Towns Residential Customers	Additional Towns Residential Customers	Total Demand
Y=1 2015	33	13	9.1%	266	101	**413**
Y=2 2016	33	13	12%	361	132	**539**
Y=3 2017	33	13	14.9%	458	166	**670**
Y=4 2018	33	13	17.8%	559	198	**803**
Y=5 2019	33	13	20.7%	660	234	**940**
Y=6 2020	33	13	23.6%	766	270	**1082**
Y=7 2021	33	13	26.5%	875	304	**1225**
Y=8 2022	33	13	29.4%	981	341	**1368**
Y=9 2023	33	13	32.3%	1098	378	**1522**
Y=10 2024	33	13	35.2%	1211	418	**1675**