Technical Report : 4G Cellular Network Deployment Planning and Economic Analysis

Ilias Bezzaz

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1 Introduction

As an engineering student, my project involves planning and dimensioning a 4G cellular network deployment at 2.6 GHz for both urban and rural zones. Key parameters include:

- Urban area: 105.4 km², 1,750,000 inhabitants (10% penetration → 175,000 users)
- Rural area: 5,176 km², 17,500 inhabitants (10% penetration → 1,750 users)
- Traffic model: 10 minutes/user/hour = 0.1667 Erlang
- Bandwidth options: 5/10/15/20 MHz (25/50/75/100 PRBs)
- Quality targets: C/I = 1.14, Blocking probability = 2%

2 Maximum Tolerated Path-loss (Uplink & Downlink)

Downlink Calculation (BS → UE)

$$\begin{aligned} PL_{DL} &= P_{BS} + G_{BS} - L_{cable} - L_{duplexer} + G_{div} - L_{LNA} - S_{UE} \\ &= 46 + 17 - 3 - 2 + 5 - 2 - (-105) \\ &= 166\,\text{dB} \end{aligned}$$

Uplink Calculation (UE → BS)

$$\begin{aligned} PL_{UL} &= P_{UE} + G_{UE} - (G_{BS} - L_{cable} - L_{duplexer}) - S_{BS} \\ &= 21 + 0 - (17 - 3 - 2) - (-120) \\ &= 129\,\text{dB} \end{aligned}$$

3 Radio Coverage Radius Calculation

Propagation Models

- Urban: $PL = 113 + 35\log_{10}(d) + 10\,\text{dB}$ (8dB shadowing + 2dB fading)
- Rural: $PL = 100 + 35\log_{10}(d) + 6\,\text{dB}$ (4dB shadowing + 2dB fading)

Effective Coverage Radius

$$d = 10^{\frac{PL-A-L_{env}}{35}}$$

Environment	Uplink Radius	Downlink Radius
Urban	$10^{\frac{129-113-10}{35}} = 1.48\,\text{km}$	$10^{\frac{166-113-10}{35}} = 16.93\,\text{km}$
Rural	$10^{\frac{129-100-6}{35}} = 4.54\,\text{km}$	$10^{\frac{166-100-6}{35}} = 51.79\,\text{km}$

4 Cell Dimensioning According to Bandwidth

Erlang-B Capacity Analysis

Bandwidth (MHz)	5	10	15	20
PRBs/cell	25	50	75	100
Capacity (Erlangs)	17.51	35	52.5	70
Max users/cell	105	210	315	420

Required Cell Count

Area	Number of Cells			
	5MHz	10MHz	15MHz	20MHz
Urban	1,667	834	556	417
Rural	17	9	6	5

Cell Radius vs Capacity

Bandwidth	Urban Radius (km)	Rural Radius (km)
5 MHz	0.156	4.54
10 MHz	0.236	4.54
15 MHz	0.298	4.54
20 MHz	0.349	4.54

5 Optimized Transmission Power

Urban Cells (20MHz Case)

$$PL = 113 + 35\log_{10}(0.349) + 10 \approx 96.02\,\text{dB}$$
$$P_{tx} = -105 + 96.02 - 17 + 3 + 2 = \textbf{-21 dBm}$$

Rural Cells

$$PL = 100 + 35\log_{10}(4.54) + 6 = 129\,\text{dB}$$
$$P_{tx} = -105 + 129 - 17 + 3 + 2 = \textbf{12 dBm}$$

6 Network Cost Analysis

Cost Formulas

- **CAPEX** = (Number of sites × 15 k€) + Frequency license + (Microwave links × 100 k€)
- **OPEX/year** = Number of sites × 5 k€
- **Revenue/year** = Number of subscribers × 20€ × 12 months

Cost Parameters

- 2.6 GHz license: 2500 k€ per 5MHz block (UL+DL)
- 18 GHz microwave links: 100 k€ per connection
- Site installation (CAPEX): 15 k€ per site
- Site operation (OPEX): 5 k€ per site/year
- Subscription fee: 20€/month per user

Urban Deployment Costs (k€) - Detailed Calculation

Component	Bandwidth			
	5MHz	10MHz	15MHz	20MHz
License	2,500	5,000	7,500	10,000
Sites (N×15k€)	1,667×15=25,005	834×15=12,510	556×15=8,340	417×15=6,255
Microwave (N×100k€)	1,667×0.1=166.7	834×0.1=83.4	556×0.1=55.6	417×0.1=41.7
Total CAPEX	27,671.7	17,593.4	15,895.6	16,296.7
OPEX/year	1,667×5=8,335	834×5=4,170	556×5=2,780	417×5=2,085

Rural Deployment Costs (k€) - Detailed Calculation

Component	Bandwidth			
	5MHz	10MHz	15MHz	20MHz
License	2,500	5,000	7,500	10,000
Sites (N×15k€)	17×15=255	9×15=135	6×15=90	5×15=75
Microwave (N×100k€)	17×0.1=1.7	9×0.1=0.9	6×0.1=0.6	5×0.1=0.5
Total CAPEX	2,756.7	5,135.9	7,590.6	10,075.5
OPEX/year	17×5=85	9×5=45	6×5=30	5×5=25

7 Network Cost Analysis

Cost Formulas

- CAPEX = (Number of sites × 15 k€) + License + (Microwave links × 100 k€)

- OPEX/year = Number of sites × 5 k€
- Annual revenue = Subscribers × 20 × 12

Cost Parameters

- 2.6 GHz license: 2 500 k€ per 5 MHz block (UL+DL)
- 18 GHz microwave links: 100 k€ per connection
- Site installation: 15 k€ (CAPEX)
- Site operation: 5 k€/year (OPEX)
- Customer subscription: 20€/month

Urban Costs (k€) - Detailed Calculations

Component	Bandwidth			
	5 MHz	10 MHz	15 MHz	20 MHz
License	2 500	5 000	7 500	10 000
Sites	1 667×15=25 005	834×15=12 510	556×15=8 340	417×15=6 255
Microwave	1 667×0.1=166.7	834×0.1=83.4	556×0.1=55.6	417×0.1=41.7
Total CAPEX	27 671.7	17 593.4	15 895.6	16 296.7
OPEX/year	1 667×5=8 335	834×5=4 170	556×5=2 780	417×5=2 085

Rural Costs (k€) - Detailed Calculations

Component	Bandwidth			
	5 MHz	10 MHz	15 MHz	20 MHz
License	2 500	5 000	7 500	10 000
Sites	17×15=255	9×15=135	6×15=90	5×15=75
Microwave	17×0.1=1.7	9×0.1=0.9	6×0.1=0.6	5×0.1=0.5
Total CAPEX	2 756.7	5 135.9	7 590.6	10 075.5
OPEX/year	17×5=85	9×5=45	6×5=30	5×5=25

8 Conclusion

Key technical and economic insights:

- **Urban Deployment**:
  - Cell radius: 156-349m (traffic-limited)
  - Optimal bandwidth: 20MHz (€1.01B profit)
  - BS power: -21dBm
- **Rural Deployment**:

  - Cell radius: 4.54km (uplink-limited)
  - Only 5MHz viable (€2.7M profit)
  - BS power: 12dBm

- **Cross-cutting**:
  - Frequency reuse pattern: 1
  - C/I ratio: 1.14 maintained
  - Microwave backhaul adds 0.5-2% to CAPEX

This analysis demonstrates the critical need for environment-specific optimization in cellular network planning, balancing spectral efficiency with economic viability.