Multi-Tier Drone Architecture for 5G/B5G Celullar Networks: Challenges, Trends, and Prospects

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Definition: Multi-Tier drone architectures are aerial systems consisting of multiple layers or types of drones

Prospects of (Multi-Tier) Drone Architectures

- Operations in **dangerous environments**
- Assisting overloaded / **damaged base stations** (BSs)
- **Replacing BSs** to reduce power consumption (low number of users)
- **Flexibility**: on demand services to meet QoS requirements by
  - Easy relocation
  - Adjustable height

Challenges of Multi-Tier Drone Architectures

- Different size, weight and power (SWAP) constraints impact operational altitude, coverage, computation and endurance capabilities
- **Low Altitude Platforms** (LAPs, small drones)
  - Increase signal strength by reducing path loss
  - Low endurance, payload, autonomy, coverage, costs
- **High Altitude Platforms** (HAPs, big drones)
  - Increase coverage and power (higher load)
  - High endurance, payload, autonomy, coverage, costs

Research Questions:

I. Does a drone deployment benefit terrestrial networks?
II. What is the impact of different configurations?
III. In what scenarios can multi-tier systems improve networks?

System Model

$h_k \triangleq altitude\ of\ drone\ k$

$d \triangleq dist.\ between\ user\ and\ BS$

$r_i = \sqrt{(x_D - x_i)^2 + (y_D - y_i)^2}$

$\triangleq horizontal\ dist.\ between\ user\ and\ drone$

$N_0 \triangleq noise\ power$

$\eta_\epsilon \triangleq$ env. loss variables with $\epsilon \in \{LoS, NLoS\}$

$a, b \triangleq$ env. LoS prob. variables

Path Loss Model

$PL_\epsilon = FPSL + \eta_\epsilon$

$\mathrm{FSPL} = 20\log_{10}\left(\frac{4\pi f_c d}{c}\right)$

Air-to-Ground (AtG) free space path loss based on Friis equation and the environment (simulation parameters!)

LoS probability: (given by ITU-R)

$$P_{\mathrm{LoS}}(h_k, r_i) = \left(1 + a\exp\left(-b\left(\arctan\left(\frac{h_k}{r_i}\right) - a\right)\right)\right)^{-1}$$

Path loss (expression):
- Distance component
- Decreases with A and LoS probability
- B is constant path loss based on carrier and non-LoS components

$$L(h_k, r_i) = 20\log\left(\sqrt{h_k^2 + r_i^2}\right) + AP_{\mathrm{LoS}}(h_k, r_i) + B,$$

$$A = \eta_{\mathrm{LoS}} - \eta_{\mathrm{NLoS}},\ B = 20\log\left(\frac{4\pi f_c}{c}\right) + \eta_{\mathrm{NLoS}},$$

Spectral Efficiency (SE)

$$SINR = \frac{P_k L(h_k, r_i)}{N_0 + \sum_{j\in\Phi_t, j\neq j} P_t L(i,j) + \sum_{l\in\Phi_l, l\neq k} P_l L_k(h_{l,r})}$$

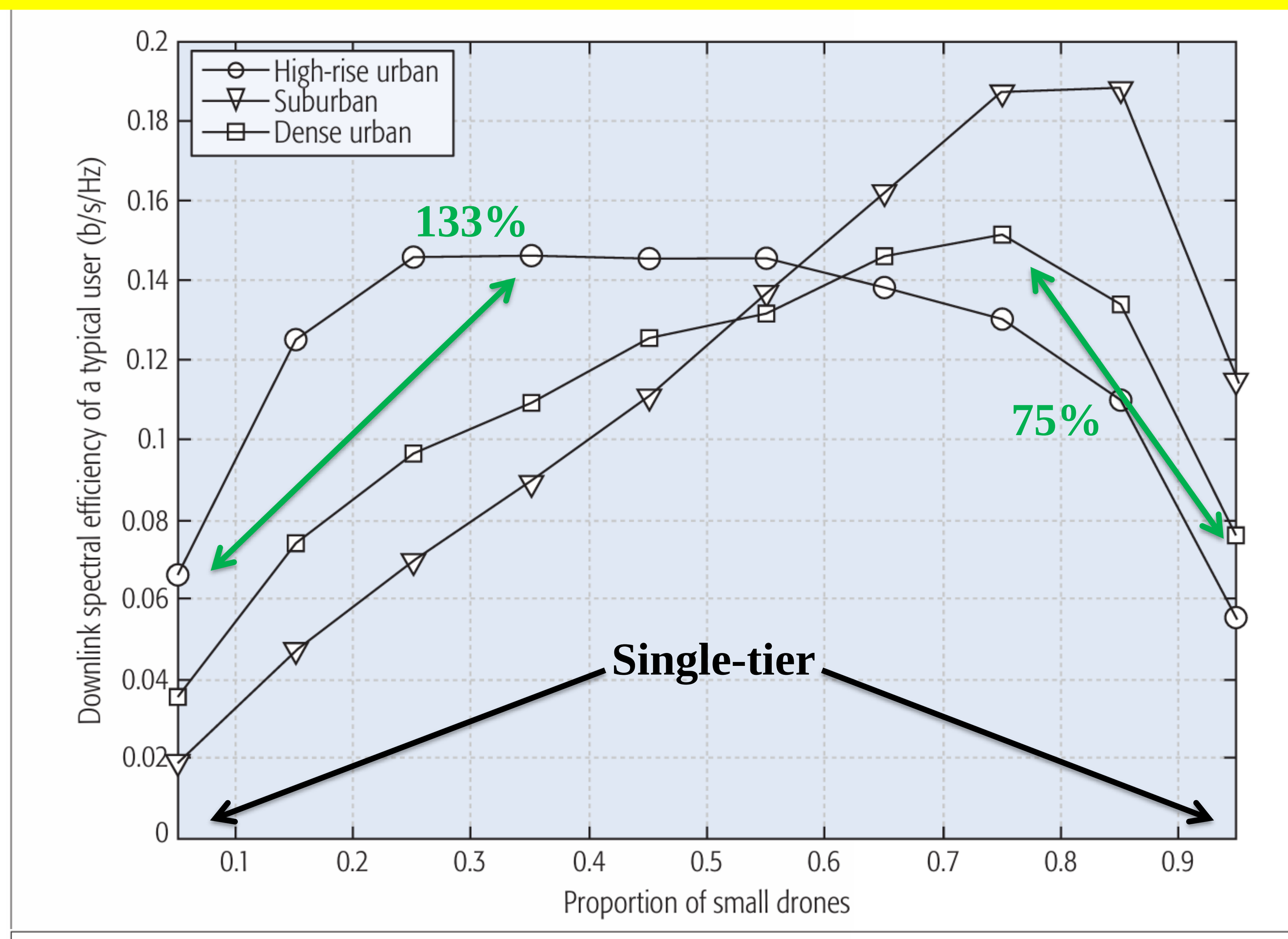
With **Shnannon**: $SE_i = \log_2(1 + SINR)$

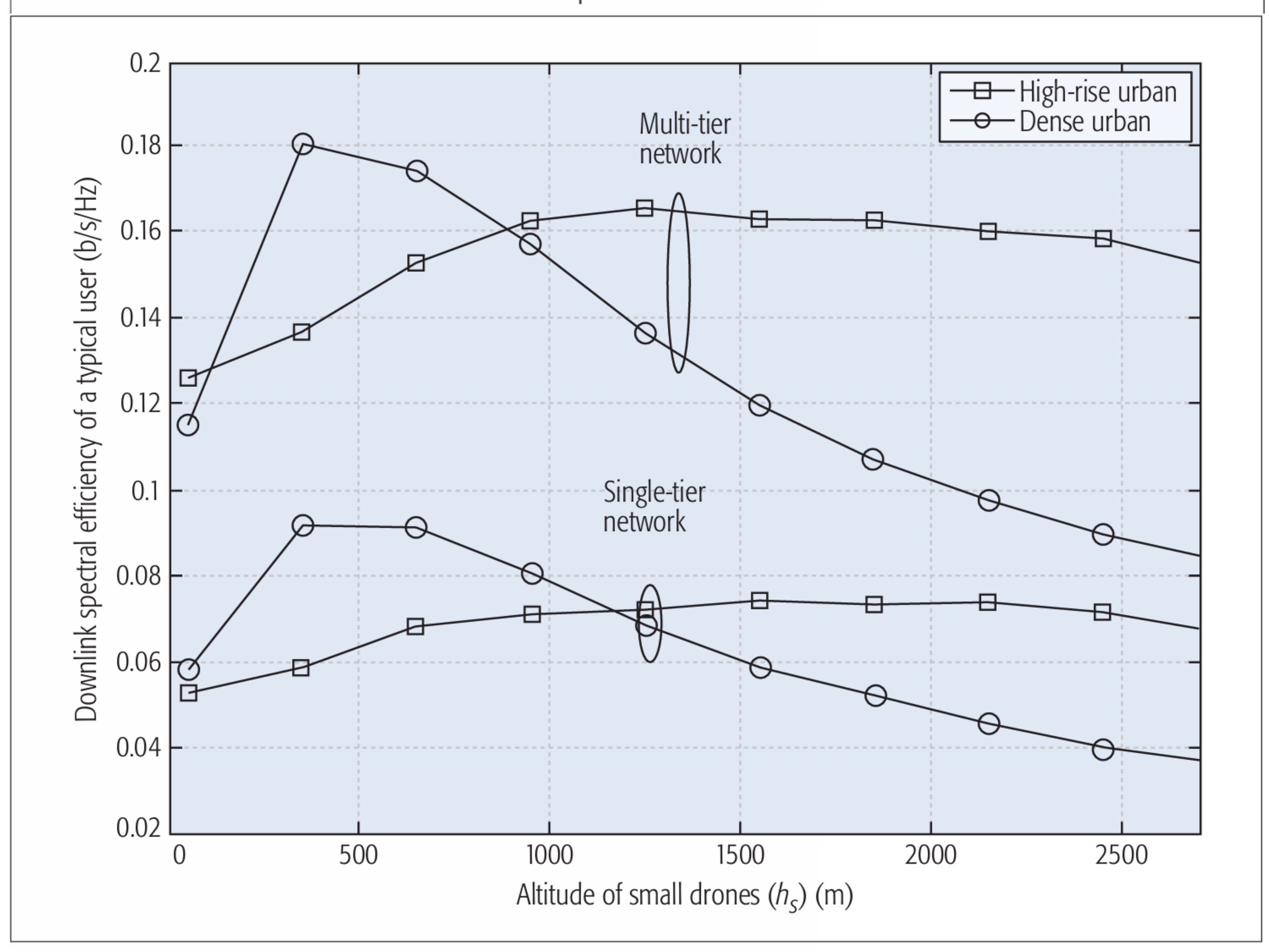
Simulation Parameters

System parameter		Value
		$(a, b, \eta_{\mathrm{LoS}}, \eta_{\mathrm{NLoS}})$
Environment	Dense urban	(12.08, 0.11, 1.6, 23)
	Suburban	(4.88, 0.43, 0.1, 21)
	High-rise urban	(27.23, 0.08, 2.3, 34)
Carrier frequency (f_c)		2.5 GHz
Speed of light (c)		3×10^8 m/s
Path-loss exponent (α)		4

Noise power (N_0)	10^{-17} W/Hz
Intensity of terrestrial BSs (λ_t)	20
Intensity of drones (λ)	10
Altitude of big drones (h_m)	3000 m
Altitude of small drones (h_s)	150 m
Power of big drones (P_m)	40 W
Power of small drones (P_s)	5 W
Power of terrestrial BSs (P_t)	2 W

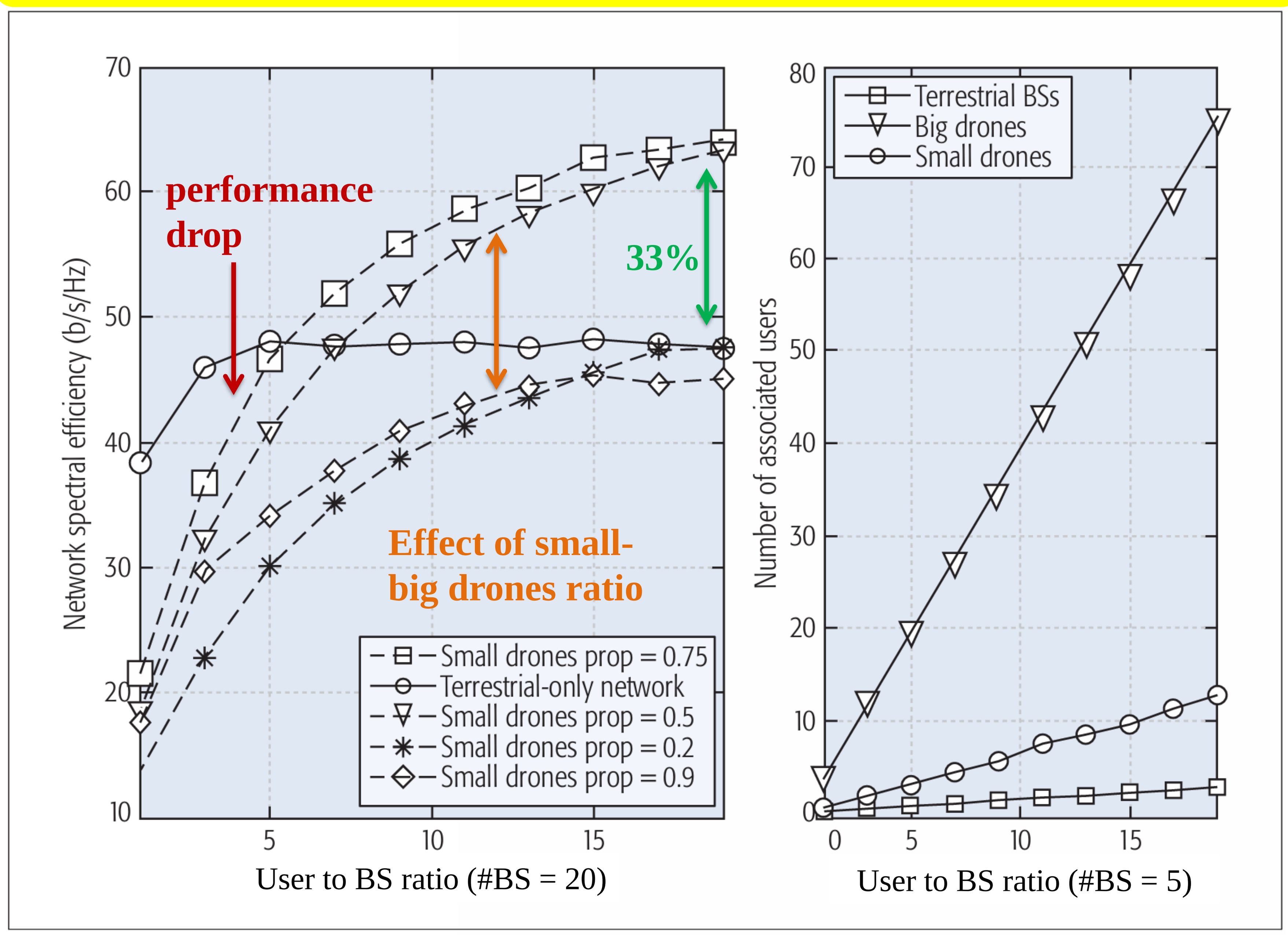
Spectral Efficiency: Multi-Tier vs. Single-Tier Drones





→ High complexity of efficient deployment
→ For both environments at least 2x increase of SE/ user for all altitudes

Spectral Efficiency : Multi-Tier Drone-Assisted Terrestrial Cellular Networks



- For high number of users SE can be enhanced immensely
- Highly complex system design choices (specific drone types and ratio) due to different environments and scenarios

Conclusions

- Multi-tier drone architectures **improve performance** in comparison to
  - Homogenous systems: under any circumstances
  - Terrestrial-only systems: for high number of users
- **High complexity** in optimal deployment depending on environment
- Requires **high level** of **flexibility** to improve service efficiently
- Future directions:
  - Investigation of heterogenous systems (more than 2 types)
  - Realistic air-to-ground channel modelling
  - Drone sharing among providers / third parties
  - Introduction of IoT applications