Mobile Communications

TCS 455

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Lecture 13

Office Hours:
BKD 3601-7
Tuesday 14:00-16:00
Thursday 9:30-11:30

Announcements

- Read
  - Chapter 3: 3.1 – 3.2, 3.5.1, 3.6, 3.7.2
    - Posted on the web
  - Appendix A.1 (Erlang B)
  - Chapter 9: 9.1 – 9.5
- Due date for HW3: Dec 18

Big Picture

S = total # available duplex radio channels for the system

Frequency reuse with **cluster size *N***

"Capacity" $C = \frac{A_{\text{total}}}{A_{\text{cell}}} \times \frac{S}{N}$

Tradeoff

$$\frac{S}{I} \approx \frac{kR^{-\gamma}}{K \times \left(kD^{-\gamma}\right)} = \frac{1}{K}\left(\frac{D}{R}\right)^{\gamma} = \frac{1}{K}\left(\sqrt{3N}\right)^{\gamma}$$

m = # channels allocated to each cell.

- Omni-directional: K = 6
- 120° Sectoring: K = 2
- 60° Sectoring: K = 1

Trunking

Call blocking probability $P_b = \frac{\frac{A^m}{m!}}{\sum_{i=0}^{m} \frac{A^i}{i!}}$.

Erlang-B formula

λ = Average # call attempts/requests per unit time

A = traffic intensity or load [Erlangs] $= \frac{\lambda}{\mu}$

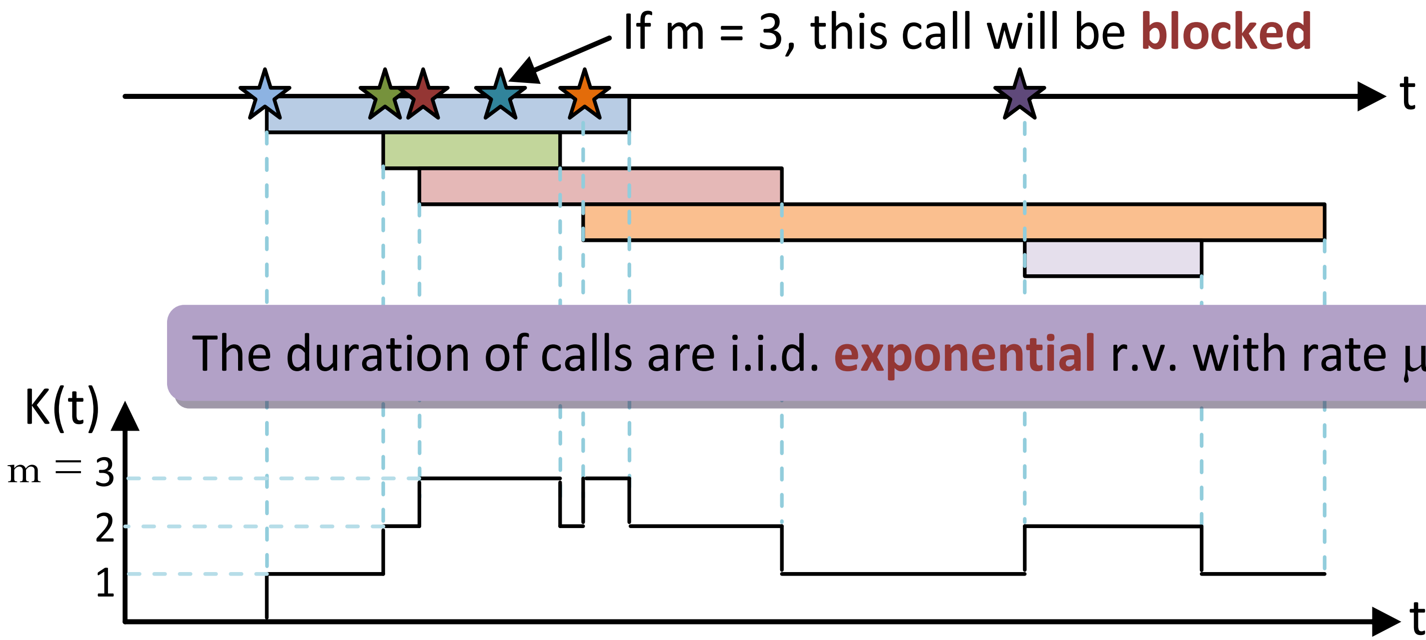
$\frac{1}{\mu} = H$ = Average call length

Assumption

- **Blocked calls cleared**
  - Offers no queuing for call requests.
  - For every user who requests service, it is assumed there is no setup time and the user is given immediate access to a channel if one is available.
  - If no channels are available, the requesting user is blocked without access and is free to try again later.
- **Calls arrive as determined by a *Poisson process*.**
- There are memoryless arrivals of requests, implying that all users, including blocked users, may request a channel at any time.
- There are an infinite number of users (with finite overall request rate).
  - The finite user results always predict a smaller likelihood of blocking. So, assuming infinite number of users provides a conservative estimate.
- **The duration of the time that a user occupies a channel is exponentially distributed**, so that longer calls are less likely to occur.
- There are m channels available in the trunking pool.
  - For us, m = the number of channels for a cell (C) or for a sector

Assumption

The call request process is **Poisson** with rate λ



The duration of calls are i.i.d. **exponential** r.v. with rate μ.

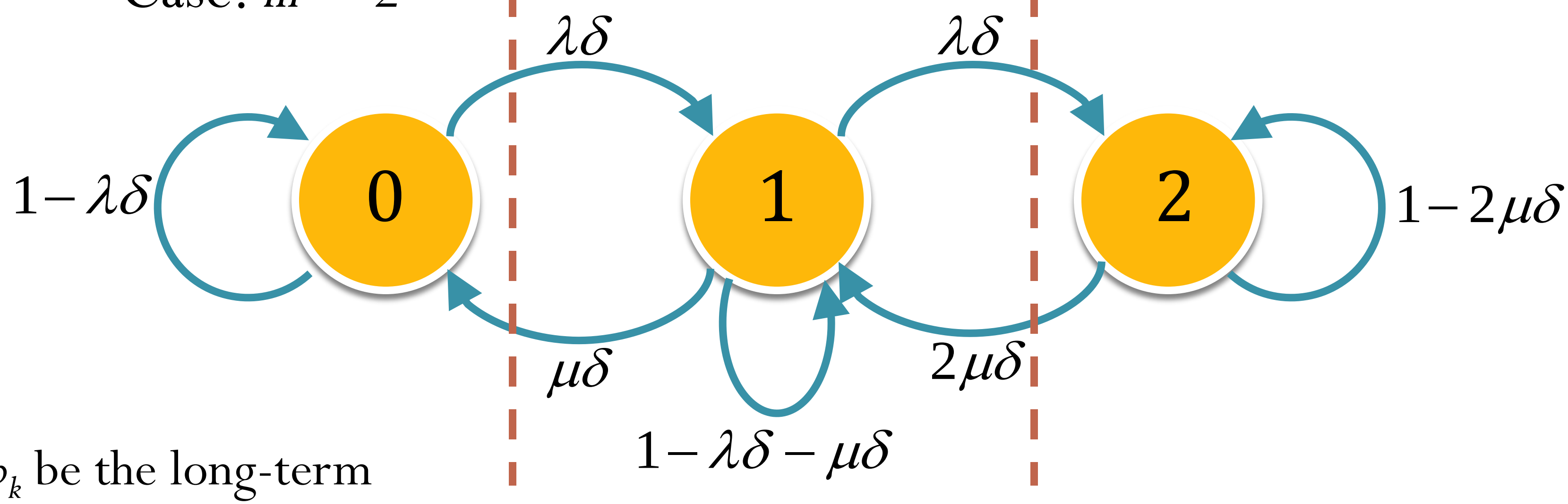
K(t) = "state" of the system

= the number of used channel at time *t*

We want to find out what proportion of time the system has $K = m$.

Small slot Analysis: Markov Chain

- Case: $m = 2$



Let p_k be the long-term probability that $K = k$.

Global Balance equations

$$\lambda\delta p_0 = \mu\delta p_1 \qquad \lambda\delta p_1 = 2\mu\delta p_2$$

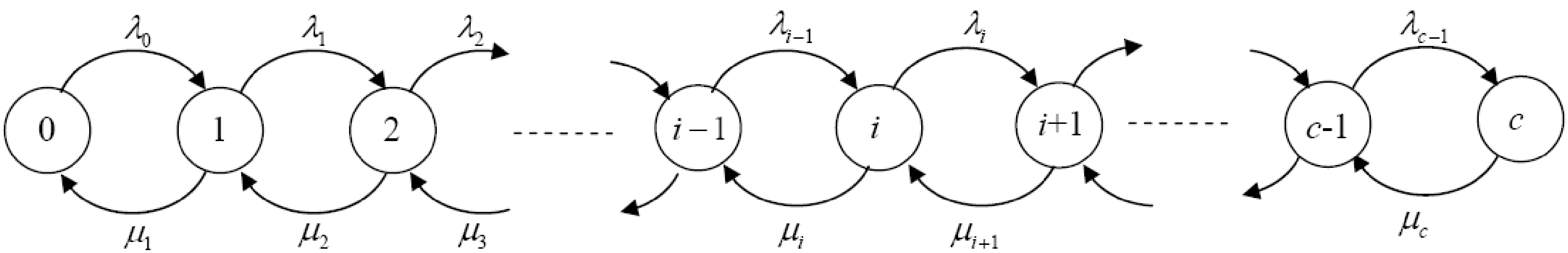
$$p_0 + p_1 + p_2 = 0$$

$$p_0 = \frac{1}{1 + A + \frac{A^2}{2}}, \; p_1 = Ap_0, \; p_2 = \frac{1}{2}A^2 p_0$$

$$p_b = p_m$$

Truncated birth-and-death process

- Continuous-time Markov chain
- More general than M/M/m/m



The stationary PMF always exists and is given by $p_i = \dfrac{R_i}{\sum_{j=0}^{c} R_j}$ where $r_j = \dfrac{\lambda_{j-1}}{\mu_j}$,

$R_j = r_j r_{j-1} \cdots r_1$ for $j = 1, 2, \ldots, c$, and $R_0 = 1$.

Parameter	Fixed WiMAX	Mobile WiMAX	HSPA	1x EV-DO Rev A	Wi-Fi
Standards	IEEE 802.16-2004	IEEE 802.16e-2005	3GPP Release 6	3GPP2	IEEE 802.11a/g/n
Peak down link data rate	9.4Mbps in 3.5MHz with 3:1 DL-to-UL ratio TDD; 6.1Mbps with 1:1	46Mbps[a] with 3:1 DL- to-UL ratio TDD; 32Mbps with 1:1	14.4Mbps using all 15 codes; 7.2Mbps with 10 codes	3.1Mbps; Rev. B will support 4.9Mbps	54 Mbps[b] shared using 802.11a/g; more than 100Mbps peak layer 2 through-put using 802.11n
Peak uplink data rate	3.3Mbps in 3.5MHz using 3:1 DL-to-UL ratio; 6.5Mbps with 1:1	7Mbps in 10MHz using 3:1 DL-to-UL ratio; 4Mbps using 1:1	1.4Mbps initially; 5.8Mbps later	1.8Mbps	
Bandwidth	3.5MHz and 7MHz in 3.5GHz band; 10MHz in 5.8GHz band	3.5MHz, 7MHz, 5MHz, 10MHz, and 8.75MHz initially	5MHz	1.25MHz	20MHz for 802.11a/g; 20/40MHz for 802.11n
Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM	QPSK, 8 PSK, 16 QAM	BPSK, QPSK, 16 QAM, 64 QAM
Multiplexing	TDM	TDM/OFDMA	TDM/CDMA	TDM/ CDMA	CSMA
Duplexing	TDD, FDD	TDD initially	FDD	FDD	TDD
Frequency	3.5GHz and 5.8GHz initially	2.3GHz, 2.5GHz, and 3.5GHz initially	800/900/1,800/ 1,900/ 2,100MHz	800/900/ 1,800/ 1,900MHz	2.4GHz, 5GHz
Coverage (typical)	3–5 miles	< 2 miles	1–3 miles	1–3 miles	< 100 ft indoors; < 1000 ft outdoors
Mobility	Not applicable	Mid	High	High	Low

Duplexing

- Allow the subscriber to send "simultaneously" information to the base station while receiving information from the base station.
  - Talk and listen simultaneously.
- We define forward and reverse channels as followed:
  - **Forward channel** or **downlink (DL)** is used for communication from the infrastructure to the users/stations
  - **Reverse channel** or **uplink (UL)** is used for communication from users/stations back to the infrastructure.
- Two techniques
  1. Frequency division duplexing (FDD)
  2. Time division duplexing (TDD)

Frequency Division Duplexing (FDD)

- Provide two distinct bands of frequencies (simplex channels) for every user.
- The **forward band** provides traffic from the base station to the mobile.
- The **reverse band** provides traffic from the mobile to the base station.
- Used in cellular

Time Division Duplexing (TDD)

- Use time instead of frequency to provide both a forward and reverse link.
- Each duplex channel has both a **forward time slot** and a **reverse time slot**.
- The UL and DL data are transmitted on the same carrier frequency at different times.
- If the time separation between the forward and reverse lime slot is small, then the transmission and reception of data appears simultaneous to the users at both the subscriber unit and on the base station side.
- Used in Bluetooth and Mobile WiMAX
- Each transceiver operates as either a transmitter or receiver on the same frequency

Problems of FDD

- Because each transceiver simultaneously transmits and receives radio signals which can vary by more than100 dB, the frequency allocation used for the forward and reverse channels must be carefully coordinated within its own system and with out-of-band users that occupy spectrum between these two bands.
- The frequency separation must be coordinated to permit the use of inexpensive RF and oscillator technology.

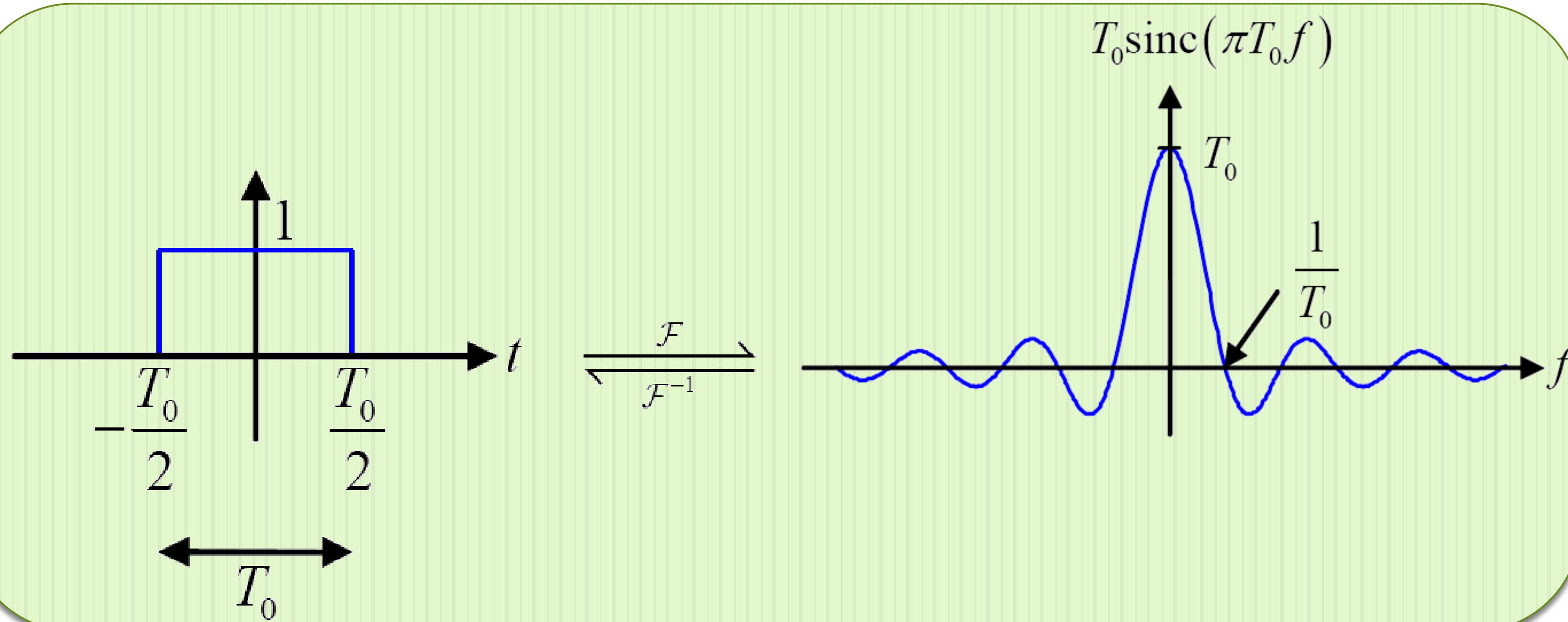
Advantages of FDD

- TDD frames need to incorporate guard periods equal to the max round trip propagation delay to avoid interference between uplink and downlink under worst-case conditions.
- There is a time latency created by TDD due to the fact that communications is not full duplex in the truest sense.
  - This latency creates inherent sensitivities to propagation delays of individual users.

Advantages of TDD

- Enable adjustment of the downlink/uplink ratio to efficiently support asymmetric DL/UL traffic.
  - With FDD, DL and UL always have fixed and generally, equal DL and UL bandwidths.
- Assure channel reciprocity for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.
- Ability to implement in nonpaired spectrum
  - FDD requires a pair of channels
  - TDD only requires a single channel for both DL and UL providing greater flexibility for adaptation to varied global spectrum allocations.

Recall: Frequency-Domain Analysis



Shifting Properties: $g(t-t_0) \xrightleftharpoons{\mathcal{F}} e^{-j2\pi f t_0} G(f)$ $\quad e^{j2\pi f_0 t} g(t) \xrightleftharpoons{\mathcal{F}} G(f - f_0)$

Modulation: $m(t)\cos(2\pi f_c t) \xrightleftharpoons{\mathcal{F}} \frac{1}{2} M(f - f_c) + \frac{1}{2} M(f + f_c)$

Example

- An example of four mutually orthogonal digital signals.