Channel Capacity

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Why Spread Spectrum?

- **Data transmission can occur with or without SS modulation - why use it?**
  - **SS can be more resistant to multipath**
  - **SS can be more resistant to Narrow-band interference**
  - **SS can promote efficient channel utilization**

Channel Utilization

- **How do mulitple users access a common resource (such as a channel)?**
  - **Example: FM Repeater or Digipeater**
    - **Use one at a time, each waits until the repeater is free, then there is a ‘free for all’**
    - **If there are too many users, then put up another repeater.**
    - **All channels are occupied whether or not they are used: Idle repeater channels cannot be used for other traffic.**
    - **If most channels are mostly idle, then utilization efficiency is very poor.**

Other types of contention

- **Dynamic assignment of channels: trunking radio system**
  - **Each user ‘requests’ a channel. When it becomes available, the user is assigned to the channel, it is marked busy.**
  - **Each channel requires a reservation of a frequency slot so that slot is avaliable when needed.**
  - **Idle slots cannot be used for other traffic.**
  - **If most slots are mostly idle, then utilization efficiency is poor.**

Orthogonal coding

- **Each slot occupies many of the channels.**
  - **Each user ‘requests’ a slot. When it becomes available, the user is assigned a code, it is marked busy.**
  - **Many orthogonal codes exist, they do not consume bandwidth when unused.**
  - **Idle codes can be used for other traffic.**
  - **If a user ‘owns’ a code, but is not transmitting, they consume no channel power.**
  - **If most slots are mostly idle, then very little average energy is consumed across the spectrum.**

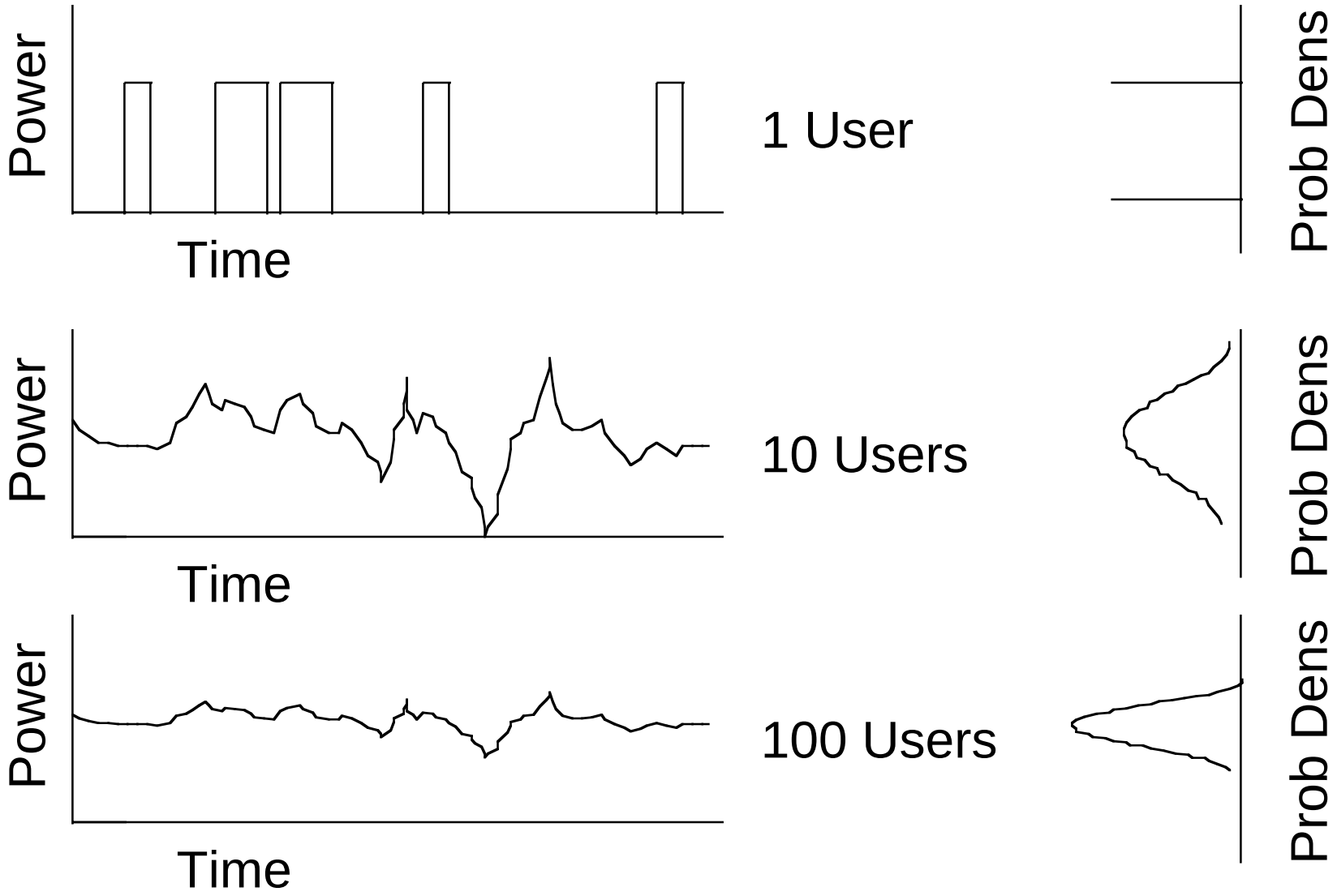
Sharing

- **Orthogonal codes (or, alternatively other FH sequences) could be used to provide multiple functions.**
  - **Each sequence needs power in proportion to it's data rate .. half the data rate means half the power is needed for same bit error rate.**
  - **If too many users need simultaneous access to the spectrum, then too much energy fills available spectrum and all users suffer bit errors.**
  - **Three strategies:**
    - **Assign codes based on peak usage.**
    - **Assign codes based on average usage.**
    - **Limit maximum codes, *delay* users beyond some capacity number.**

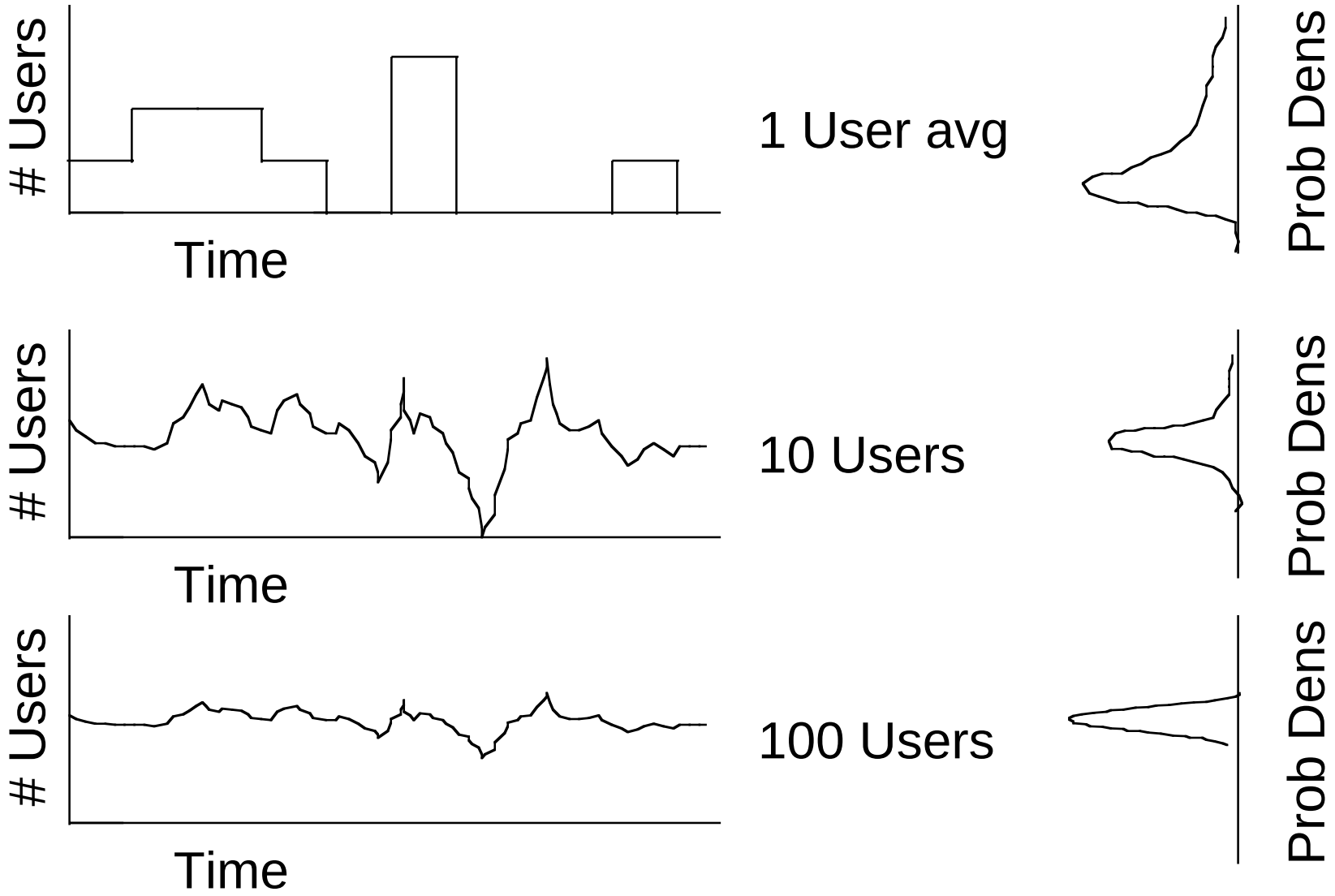
Peak use / Average use

- **If there are many users, then statistically the channel power consumption tends towards the average.**
  - **The more users, the higher the probability this is true. (Gaussian distribution).**
- **In addition, users requesting channels arrive at an average rate, with some variation in when they arrive.**
  - **The more users, the higher the probability that they arrive near the average rate (Poisson distribution).**
- **These two factors can lead to efficient utilization of channel capacity.**

Channel Power Consumption



User arrival rate



Delaying Users

- **In order to minimize peak consumption, *delay* users until a channel becomes available.**
  - **Problem is well-studied in Telephone industry.**
  - **If we delay a user, then the Poisson distribution holds. Tables for Erlangs capacity vs. blocking probability and number of trunks are readily available.**
  - **1 Erlang of traffic = one trunk completely busy all the time.**
  - **Translate: 1 trunk = 1 code**

Erlangs to Users

- **If each user holds for 6 minutes, and calls once per hour, they consume 6/60 = 0.1 Erlangs of capacity.**
- **Mapping this to data usage is tricky, since data usage statistics don't follow telephone usage statistics too well.**
- **Factor this with the User's power density. If they only have data to send 10% of the time, then they use 0.1 * 0.1 = .01 Erlangs.**
- **A few trunks handle a lot of users...most of the time.**

Trunk Loading Capacity

	Grade of Service		
Trunks	P=.001	P=.01	P=.1
1	0.003	0.011	0.106
2	0.044	0.15	0.531
3	0.192	0.436	1.1
4	0.428	0.822	1.75
5	0.739	1.281	2.444
6	1.11	1.79	3.14
7	1.52	2.33	3.89
8	1.97	2.91	4.67
9	2.45	3.5	5.42
10	2.97	4.14	6.22
11	3.5	4.78	7.03
12	4.03	5.42	7.83
13	4.61	6.11	8.64
14	5.19	6.78	9.47
15	5.78	7.47	10.28

Capacity
in Erlangs

Source: Reference Manual for Telecommunications Engineering

Conclusion

- **Trunking system dramatically improves channel utilization and grade of service.**
- **Spread Spectrum system improves upon trunking capacity by factor of average user channel density.**
- **SS provides significantly more data capacity with higher grade-of-service than traditional channelized techniques employing non-coordinated point-to-point links.**
  - **Example: PCS cellular system**

Example

Collecting idle time among trunks (all in a group) vs. same number of independent trunks:

Blocking Probability	1 Trunk	10 Independent trunks	10 Grouped trunks
P=0.01 @ 6 mins/hr	0.011 Erlangs 0.11 Users	0.11 Erlangs 1.1 Users	4.14 Erlangs 41.4 Users
P=0.05 @ 6 mins/hr	0.053 Erlangs 0.53 Users	0.53 Erlangs 5.3 Users	5.42 Erlangs 54.2 Users

Between 10x and 40x improvement in Capacity