ECE 5325/6325: Wireless Communication Systems
Lecture Notes, Spring 2013

Lecture 21

Today: (1) Presentation Day Schedule (2) Prep for Exam 3 (3) Packet Radio

1 Presentation Day

Please sign up for a presentation slot for you and your project team.

Your project presentation should provide both the broad overview of your system design, as well as the details necessary to specify the details so that others can verify your link budgets and judge whether they will be reliable wireless communications systems. To do this, I am asking you to provide in your presentation three specific types of slides:

1. **System overview slide**: graphically depict the transmitters and receivers and links (with directional arrows) which exist in your system, explaining how data gets from a user to the outside world.

2. **Link budget slide**: Have one of these slides for each type of link in your system. This slide contains your assumptions for: path length, path loss exponent, fade margin, antenna gains, transmit power, receiver noise figure, bandwidth, modulation, probability of bit error. Note some of these are redundant. Explain what assumptions you made, and why the link is reliable.

3. **Multiple access control slide**: Explain how multiple users' devices access the channel, and why it is reliable. Will there be FDMA, TDMA, CDMA? Will there be random access, or controlled access? During the busiest period and most congested spot in the disaster area, what will be the probability of blocking, collision, or delay be?

These three are the meat of your presentation, and should be your focus, both as a presenter and as a judge. Additionally, your system may have other features which you want to present, such as low user device cost, ease of adoption, low infrastructure cost, etc. However, these will be determined by the link budget assumptions you make (e.g., how many antennas, what receiver noise figure, transmit power, etc.), so I want us to be sure to present these details, and not just a cost estimate.

Your written report should contain these three "sections" as well. Please present the link budget equation and show that it is sufficient to meet the requirements you have assumed. Your written report will be on Canvas on the morning of April 18 (by 9:10am, the start of the "class" that we will not hold). Other students will be able to read your report, in particular, before and during the presentation session.

I'm guessing about 16 groups of 5325 students, and about 5 6325 groups. Because of the high number of presentations, we need to have two parallel sessions, one for 6325, and one for 5325. If you are in 5325, you will present your design in the 5325 session. However, you will need to attend as much of the 6325 session as possible, because you will be judging the 6325 presentations. Alternatively, if you are in 6325, you will present your design in the 6325 session and be required to judge as many of the 5325 presentations as possible.

Your presented slides should be uploaded to Canvas, the deadline is 5pm on April 18.

2 Exam 3 Prep

Exam 3 covers lectures 12-19, and homeworks 6-9. Exam 3 will involve about 1/3 "non-numerical" problems, *i.e.*, short answer and multiple choice. The other 2/3 will be calculation problems. My best advice is to read all of the lecture notes again, and to read all of the required readings and the MUSE videos. While reading them, take detailed notes (with paper and pencil!), which you may include in your portfolio.

3 Packet Radio

It is also called multiple access control, because we are designing a protocol for multiple users to share one channel (the "medium"). We have talked about multiple access throughout this semester already

- Frequency-division multiple access (FDMA)
- Time-division multiple access (TDMA)
- Space-division multiple access (SDMA): e.g., the cellular concept
- Code-division multiple access (CDMA)

This lecture is about **control** of medium access, *i.e.*, MAC. We will in this lecture:

- Learn how aloha and slotted aloha packet radio networks work, and their capacities.
- Learn what the "hidden terminal problem" is.
- Learn how 802.11 networks schedule traffic, and their capacities.

The first topic motivates the problem with packet radio, which then motivates why it can be more efficient to employ scheduling in a MAC protocol. However, it would be great to avoid the need for a controller or centralized scheduler.

1. No control: Some wireless network protocols do not attempt to exercise control over when users offer traffic to the channel. In these cases, when two users transmit at the same time, their signals collide and can both be lost (*i.e.*, not recoverable at the intended receiver). Actually, depending on the signal to interference ratio (SIR), a signal may be able to be received despite the fact that another interfering signal overlaps with it. Further, as we saw in the spread spectrum lecture, some modulation methods make it easier to recover the desired signal when it overlaps with other interfering signals.

2. Some control: An 802.11 (WiFi) access point also exercises control over the users that communicate with it. But it has no control over where in space the next access point is that is also using the same channel.

I assign the reading [1] because Dr. Abramson and the University of Hawaii addressed the design of a data communication system from scratch, like you are assigned to do for the semester design project. They did this 40 years ago, but we still use the analysis that they did in wireless networking systems today, because they did such a good job of presenting the fundamental tradeoffs in the design of packet radio systems.

The problem that Dr. Abramson had was that the University of Hawaii wanted to connect its campuses on different islands to a central server (called the "menehune" in the paper), which itself was connected to the ARPANET. However using telephone line connections just was such an inefficient and expensive method to do so. Essentially, it was expensive to reserve a dedicated telephone channel for each computer terminal in the Hawaii system. It ended up being much cheaper to use radio communication, on a single channel with a higher bit rate (24 kbps!).

3.1 Aloha

This protocol is called "aloha" after the Hawaiian word. In this single channel, each terminal, when it had data, would just transmit a fixed duration (τ-length in time) "packet" of data. If two terminals happened to send packets that overlapped in time, you might have them collide and get neither packet, but that if this happened, both terminals would just retransmit later. There is a reverse channel on which the receiver acknowledged any packet from any sender that was (correctly) received. This positive acknowledgement is abbreviated as "ACK".

Let the average number of data packets per second (from all senders) be r. Again, τ is the duration of a packet. Then the average total utilization of the channel is $r\tau$. A utilization of $r\tau = 1$ would be perfect utilization. **The result of [1] is that the utilization of the channel is, at most, 18.4%**. At a higher r (and thus utilization), the number of collisions increases faster in a way that reduces the rate of successfully received packets. This maximum utilization is also referred to as the capacity of an aloha packet radio system.

Note that in this protocol, the receiver exercises very little control. It is the senders who decide when to transmit.

We also have a formula for the maximum number of active terminals (or users) sending packets to the server. This maximum is k_{max},

$$k_{max} = \frac{1}{2e\lambda\tau}$$

where e is the base of the natural logarithm, λ is the average rate at which each terminal sends packets to the server (in packets per second), and τ is the packet duration. Note that we use "active terminals" to describe terminals that send packets right now at the average rate of λ per second. There might be other "inactive terminals" which are not sending packets at all at this time.

3.2 Slotted Aloha

Abramson also studied a variation of the aloha system in which terminals were synchronized and could agree on non-overlapping "slots", that is, times during which packets could be transmitted [2]. That is, rather than transmitting at just *any* time, a terminal would wait for the next slot's start time. By having all packets transmitted starting at the slot start time, there will be fewer collisions. Abramson showed that this simple modification allows the maximum utilization to double, to 36.8%. The maximum number of active terminals becomes $k_{max} = \frac{1}{e\lambda\tau}$, also double the result for regular aloha.

The only problem is that, now, each terminal must be synchronized to a clock. The difficulty depends on the synchronization requirements.

Slotted aloha is slightly more controlled, in that each terminal is synced to the same clock, and must start transmitting only at the start of a slot.

Example: How many active users could you support?
How many active users could you support on a 1 MHz channel using a packet radio system? Take, in this example, a QPSK system with SRRC pulse shaping with $\alpha = 0.5$. For this example, use the same packet rate and duration used in the original aloha system – 704 bits per packet, and a packet generation rate of 1 per minute. Calculate both for aloha and slotted aloha.
Solution: The bit rate is 1 MHz $(\log_2 4)/(1 + 0.5) = 1.333$ MHz. For 704 bits, this would take a duration of 0.53 ms. Using aloha,

$$k_{max} = \frac{1}{2e\lambda\tau} = \frac{60}{2e(0.0021)} \approx 20.9 \times 10^3$$

For slotted aloha, the max number of users would double to 41.8×10^3.

References

[1] N. Abramson. The aloha system – another alternative for computer communications. In *Proceedings of the Fall Joint Computer Conference*, pages 281–285, 1970.

[2] N. Abramson. The throughput of packet broadcasting channels. *IEEE Transactions on Communications*, 25(1):117–128, 1977.