Learning Telecommunications Principles in a Dark Room

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Abstract

What can you learn about communication protocols in a dark room? Maybe a lot! In an introductory graduate course in Telecommunications Principles at Murray State University, we take students with extremely diverse backgrounds and skills, and put them into a virtual dark room for a series of exercises, and tell them to communicate with only a simple 'buzzer' signaling device. By the time they finish the exercises they have created a simple but robust binary encoding protocol, created addressing schemes, and developed network traffic management mechanisms. In the process, they grapple with concepts such as capacity and efficiency, synchronization, collisions, and error control. In a course with the dual mission to teach the fundamentals of telecommunications to business management professionals, and at the same time remind information technology specialists and telecommunications engineers how to talk about their fields in layman's terms, one of our best tools is a dark room.

Introduction

In 1997, Murray State University (MSU), a midsize university with just over 10,000 students, was given the task to develop a state recognized and sponsored program of distinction in Telecommunications Systems Management (TSM). The objective of this program was to establish a high-quality, interdisciplinary technical and business, undergraduate and graduate curriculum in telecommunications and networks. The perquisites for enrollment in the MSU graduate TSM program include holding a bachelor's degree in any field. The program recruits and enrolls a well balanced mix of managers, telecommunications technicians, information technology specialists, and people with no background at all in the field of telecommunications. This subject of this paper is a teaching/learning technique we call the 'Dark Room'. The 'Dark Room' series of exercises is a key part of an MSU course titled Telecommunications Principles, which is a mandatory first class for most of our program's graduate students. Given the wide variety of backgrounds in our students, a key purpose of the course is to get them all speaking in the same terms, and the Dark Room exercises are a key element in accomplishing that task. Since our TSM courses are taught online, the dark room is virtual, not physical.

This paper describes the goals, implementation details, outcomes, and lessons learned from the conduct of the Dark Room exercises over many semesters. It includes a purpose and detailed description of each progressively more complex exercise; a description of how and why the exercises evolve from individual student efforts to group work; and examples of student and faculty solutions. Anecdotal student feedback is reported, and plans for more organized feedback collection are described. Most importantly, the paper describes why we use these exercises, what students learn from them, and why we think other programs could benefit from them.

The Dark Room concept and its use at MSU have had many contributors. The concept's exact creator is uncertain, but it has been in use at MSU since the birth of our TSM curriculum in 1998 in courses that were first taught by Mr. John McLaren. A thorough review of related technology and pedagogical literature does not reveal similar concepts being used in other institutions. We strongly suspect that other institutions and organizations have, and do use similar concepts, but they have not taken the time to document and publish their techniques and results.

Objectives

The dark room exercise concept is a critical element in our TSM601 Telecommunications Principles course. TSM601 is an overview of telecommunications industry technology and applications including some history, technology fundamentals, standards, and protocols. The class focuses on the underlying principles of telecommunications systems and networks. The overall objective of the course is to provide the student with the concepts necessary to readily understand the communication systems in use today. As a future manager in the industry, the student will need the ability to use layman's terms to describe the problems and solutions in communicating over distances to management and non-technical clients.

First Steps

This is a course about fundamental principles. We do not start with network or communications models. We start with counting. The first 2-3 hours of the course are devoted to a review of (in some cases an introduction to) binary and hex numbers, and converting between them and decimal numbers. When this topic is introduced our students with business/management backgrounds often challenge the relevance of the topic. Our students with technical backgrounds often roll their eyes before claiming they are already experts in the topic. While many people are comfortable with the concept of binary numbers, few have studied them formally, or used them regularly. At the completion of about three hours of discussion and practice, all of our students are on an even footing and comfortable with the fundamentals of counting in, and converting between binary, decimal and hex numbers.

The next topic that we tackle is binary encoding, and again we start very simply. How many different things can you represent with just a zero and a one? The answer of course is that it depends on how large a binary number you are willing to use. Clearly you can represent any two characters, values, or objects with just a zero and a one, if you have just two things to represent. A zero can represent an 'A', and one can represent a 'B.' A zero can represent 'New York' and a one can represent 'Los Angeles.' With a two place binary number we can represent four things using 00, 01, 10, and 11. Finally, building on this concept, we learn that we can represent $\mathbf{2^n}$ things with a binary number of '**n**' places, or columns. The classic test question is then: 'How many places or 'binary digits' do we need to represent the 26 characters of the English Alphabet? The solution generally follows these steps:

If $\mathbf{n = 4}$, then $\mathbf{2^n = 16}$, which is not enough possibilities to represent 26 letters

If **n = 5**, then $\mathbf{2^n = 32}$, which is more than enough possibilities to represent 26 letters with six extra representations

Our final introductory topic is the concept of the binary or on-off nature of electronic switches. This discussion does not include any significant details of how transistors or modern electronic switching mechanisms work. It simply describes that an electronic switch, whether it is a room's light switch, a transistor, or a register in a computers CPU can be thought of as being in one of two states or values: either off-or-on, positive-or-negative, or zero-or-one.

With these three topics completed: binary and hex numbers; the general concept of encoding information in a binary form; and the on-off nature of electronic switches; and without any detailed discussion of standard encoding schemes such as ASCHII or Unicode, we are ready for the first Dark Room exercise.

The following sections will follow a general format including: a) the exercise instructions and goals as provided to the students; b) characterization of the exercise, its intent, and typical student responses; c) examples of student and/or faculty responses. The example student responses come from a variety of students and are close to exact quotations, but some paraphrasing has been done to make the examples more readable and concise.

Dark Room Exercise 1

With the introduction of the first exercise we describe the environment and an initial simple task:

> *Five or six people are seated at desks in a completely dark room, unable to see one another, or speak to one another. The only mechanism for communication in this dark room is a button on each desk. Whenever the button on any desk is pressed, it causes a signal device (think of a buzzer initially) in the room to make a sound that lasts 1 second. Using only this buzzer, describe a system that allows one of the people in the room, to communicate a number between 0 and 50, simultaneously to all the other people in the room.*

The exercise instructions include guidance that a solution must be in layman's terms and not exceed one, single-spaced page. Students work individually on this exercise and typically have one week to complete it. After they read the assignment for the first time, a common question from students is whether they can assume that the people entering the dark room are trained and ready to use the system, and the answer is yes.

Without describing it to the students as such, this problem is a one-to-many, and master-to-slave communications problem. In the stated task, only one station is required to send a message. The message is broadcast with an audible tone that each of the other people/stations will hear. No addressing is necessary because the message is not targeted to a particular receiver. Collisions are not an issue because only one person has a message to transmit and controls the start and end of all communications. There is no stated requirement or goal that the system be efficient. No encoding method is specified. Including the requirement to communicate a zero purposely complicates the encoding scheme for the student in that it prevents them from using a purely direct one-for-one encoding of the numbers to be transmitted since they must have a way to communicate the zero other than using just silence.

Student solutions usually include one of three general encoding schemes:

1. Direct Correlation: Systems that call for a mostly direct correlation between buzzes and the number to be transmitted. In other words, one buzz equals the number 1, two buzzes equal the number 2, and so on. This is not an entirely direct correspondence because they must be able to transmit a zero. Students may use one buzz to represent zero and then have a 'number to be transmitted plus one buzz' rule to represent the rest, or they may have a direct correspondence for one to fifty and have '51 buzzes' represent zero. Either of these methods is fairly straight-forward for the student to understand and easy for them to describe. This type of system is clearly not efficient, nor would it be easy to use as the sender and receivers could easily lose track of how many buzzes have been transmitted.

2. Six Bit Word: The most common method of encoding adopted by students is to use a simple six binary digit or '6 bit' number to represent the decimal number to be transmitted. Students are again faced with whether to encode the zero as '000001' or '110011'. With this method, students begin to struggle with the concept of synchronization. How are the receivers to distinguish between the messages '001001 and '000101'? Not all students recognize this as an issue at this point, but if they do not address the idea of 'timing' or 'beats' or 'one second pauses' to convey the proper number and location of zeros in a message they won't receive full points for the assignment which helps ensure they address this in the next exercise.

3. Three Bit Words: A third common approach to the exercise is to use a 3 or 4 bit binary number to represent the tens column of the decimal number, and a 4 bit binary to represent the ones column. If the number to be transmitted is 35, the '3' of the tens column could be transmitted as a '011' followed by the '5' of the ones column being transmitted as a '0110'. As before, students must decide how to handle transmitting a zero, and they have a more complex synchronization issue as the receiver must be able to distinguish between the transmissions of the two elements.

Conceiving of an approach for dealing with the first Dark Room task is often easier for students than describing their approach. Limiting themselves to a single page and layman's terms generally appears to be much more difficult for the students with technical backgrounds. These students frequently try to describe complex communications protocols that they have been exposed to, and they will rarely use what we consider to be satisfactory layman's terms. Many students will exceed the one page limit and still fail to adequately describe their approaches. If students take an approach similar to #1 above, they do not receive deductions for inefficiency, but they are warned that system efficiency will be graded in later exercises and that they should consider more efficient approaches. The clearest and highest scoring solutions, such as the following examples, rarely take more than half of a page.

Example Student Solutions for Exercise 1

Direct Correlation:

If a series of numbers have to be communicated by only using a buzzer I think one could just use the following equation: X+1=amount of times buzzer is rung. X being the original number or numbers needed to communicate. For example, if my number is 23, then the buzzer must be rung 24 times or 23+1=24. The range of numbers is zero to fifty that is why I am adding one to each number or otherwise it would be too simple and just ring the buzzer the exact times of the number.

Six Bit Word

For my system I will count using binary. Everyone in the room can count time in seconds. Everyone expects a series of beeps or silence to come in 8 second groupings. The first beep means we are starting the communication flow. If the number we are trying to send is 0 then after the starting beep, there will be a series of 6 seconds of silence followed by one more beep signaling the end of the number transmission. A '1' in the examples means there is a beep. A '0' means there is not a beep. The ones on each end represent the starting and ending of transmission. Note: There will always be a '1' at the beginning and ending. The middle six positions represent the number we are sending. These will vary depending on the desired number.

10000001 = 0	*10001001 = 4*	*10011001 = 12*
11001011 = 37	*11100101 = 50*	

Dark Room Exercise 2

We are still in a dark room. There is still only a single person/station that sends out messages, but now we need a method for targeting a specific receiver among the other five people/stations in the room. Update your system so that the sender can designate a specific receiver for a message. Obviously, in our simple environment, all the other people/stations will still hear the message, but they must be able to know when the message is meant for them, and when it is not meant for them. In addition to describing your system, provide example messages for the following: Send the sequence '3, 15, 45' to person/station #3; and send the sequence '0, 20, 50' to person/station #5.

Dark Room Exercise number 2 is an example of a one-to-one communications task and it is still a master-slave system as only one station transmits and determines when a message is to be sent. In this exercise, students must consider addressing for the first time, but collisions are still not an issue because there is still only one sender. New synchronization or timing issues in Exercise 2 include that the student's systems must now distinguish between addresses and data, distinguish between sequential parts within a message, and distinguish between messages addressed to different receivers.

After group discussions about solutions for Exercise 1 most students that used a direct correlation approach for Exercise 1 drop it in favor of bit based approaches when continuing with the Dark Room Exercises. Most students adopt a 3 bit address to represent each of the stations in Exercise 2. While it is not mandated, many students also assign a 3 bit address for the sender's station, anticipating that future requirements will include peer-to-peer messaging between all stations.

Example Student Solution for Exercise 2

For this exercise I will build on my binary counting system from the first exercise. This time I will have 9 beeps in the middle of the starting and ending beeps. There will be a total of 11 second intervals of communication. I will show the 11 seconds with the diagram below.

10000000001

"A '1' means there is a beep. A '0' means there is not a beep. The ones on each end (position 1 and 11) represent the starting and ending of transmission. The first three blue digits (positions 2, 3 and 4) will identify the destination of the message. The next six red digits (positions 5-10) represent the number we are sending. These will vary depending on the desired number. The sender is station Number 1 and the other 5 stations make up the 6 total stations in the room.

To send the sequence '3, 15, 45' to person/station #4 – I send: (color coded for ease of reading)

11000000111 11000011111 11001011011

Dark Room Exercise 3

We are still in a dark room, and there are still up to six stations in the room, but now every person/station is required to send out messages, and must be able to designate/target a specific receiver in the room. Update your system so that the sender can designate a specific receiver for a message. Obviously, in our simple environment, all the other people/stations will still hear the message, but they will need to know when it is for them, and when it is not meant for them. Further, the receiver must know who the message is from. The sender may have to send a message to them self.

In this exercise, an important issue to work out is how people in a dark room know that someone has a message to send (you can't see them raise their hand!), and who goes first when two or more people have messages to send at the same time. Your system must be able to avoid 'collisions' - that is two stations starting to send at the same instant and thereby garbling both messages. We are still not concerned about efficiency, so keep it simple and focus on guaranteeing there will be no collisions.

As an option, you may include a second signaling device at each station that can be programmed to make a single unique sound with a one second duration. Each station would still have a standard 1 second buzzer, but now you may add a second device that can make a single different sound (honk, bell, whistle, etc.) at each station.

In addition to describing your system, provide example messages for the following: Send the sequence '5, 25, 40' from person/station #1 to person/station #3; send the sequence '0, 15, 50' from person/station #2 to the person/station #4; and send the sequence '10, 23, 49' from person/station #3 to the person/station #5.

Dark Room Exercise number 3 is an example of a many-to-many communications task with peer-to-peer relationships between stations as any station can initiate a message at any time unless synchronization restrictions are imposed.

The concept of network collisions is introduced in this exercise. Some students may find it difficult to grasp this concept or find solutions for it. Other students will not readily accept the premise that two stations can simultaneously begin to transmit at exactly the same instant of time, or that users could not recognize the collision and distinguish between the two or more separate messages being transmitted. It is essential that all students eventually understand, accept and work with the concept of collisions and their disruption of messages. At this point, we have not previously discussed the concept of network logical topologies in the course and Exercise 3 is an excellent precursor to that. If they have dealt with collisions in the Dark Room Exercises, students will be well prepared to discuss token rings, and other collision prevention, detection, or avoidance mechanisms

A more subtle issue that the students should deal with in Exercise 3, which is often overlooked in their solutions, is network fairness. How do they ensure that a station does not dominate the network with an unending stream of messages, preventing other stations from transmitting their traffic? If students fail to address this issue in their Exercise 3 solutions it is discussed during the critiques and emphasized heavily in Exercise 4.

Exercise 3 is further complicated by the introduction of an optional second signaling device for every station. Students will often assume that there is a single key function for this second device and that their solutions will not be acceptable unless they use it. This is actually not true as students can meet all the requirements of the exercise without using a second device. The second device with a unique sound was introduced into the exercise to determine if students would recognize and use the device as a means of producing a more efficient system. A basic possible function of this device is to identify the sender of a message with a single position, six variation bit.

Without the second signaling device student solutions will typically start with simply injecting the 3 bit sender's address into their solution for Exercise 2 and this is an acceptable approach. With the second signaling device however, the 3 bit sender's address could be replaced with the single bit equivalent unique sound identifying the sender – a slight improvement in system efficiency. Some students will attempt to use the second signaling device as part of a collision avoidance mechanism where this device announces that they have a message to send. This approach is generally only effective if you accept as assumptions that: a) If two or more transmissions are started at exactly the same instant in time the sounds won't make one another indistinguishable; and b) The stations have a satisfactory method of determining when to retry their transmission.

A Token Ring like mechanism of turn taking or strict ordering of turns is the most straight forward approach for students to take to avoid collisions and the simplest for them to describe. Many students will assume away the issue of collision detection, and concentrate on a mechanism for restarting transmissions. Overall, this is generally where we see the most points deducted for student solutions for all of Exercises 1, 2, and 3.

Example Student Solution for Exercise 3

> *I will use the second signaling device for each station, each with a distinct sound, which I will refer to as the Sender Buzzers because they notify everyone in the room of the Sender. The Sender Buzzer for each Station will be the following: Station 1 - cat meow, Station 2 - dog bark, Station 3 - ding, Station 4 - fog horn, Station 5 - phone ring.*
>
> *The Sender Buzzer will be the first part of each message, followed by the receivers 3 bit address, followed by a two second pause before the numbers are transmitted. In my examples, 'BZ' (short for buzz) is the same as a one, and 'SI' (short for silence) is the same as a zero. So, a message from Station 3 to Station 2 would begin like this: DING-SI-BZ-SI-SI-SI. Everyone must continue to be on the same beat as they were when the "session" started, even when the group is switching to a new sender.*
>
> *To avoid collisions, each station must take turns "talking", so they must have a way to recognize when someone else has a message and when it is their turn to talk. To do this, everyone will memorize which buzz goes to which station. Every Station will then have to go in order of their decimal station number from lowest to highest. For example if Station 4 and Station 3 both try to start a message, Station 4 must let Station 3 go first because they need to go in decimal order. Or, if Station 1 and Station 3 are the only ones in the room who want to send a message, Station 1 must go first because it is first in the hierarchy. Or, if everyone hears a meow and a ding at the same time everyone, including station 3, will recognize that the meow must go first, so Station 1 will continue its message. At the end of each Station's message, they will play the Sender Buzz again to signal that their message is complete and it is someone else's turn.*
>
> *Example: Sequence 5, 25, 40 from Station 1 to Station 3*
> *Meow-SI-BZ-BZ-SI-SI-SI-SI-SI-BZ-SI-BZ-SI-SI-BZ-BZ-SI-SI-BZ-SI-SI-BZ-SI-BZ-SI-SI-SI-Meow.*

Dark Room Exercise 4

> *Exercise 4 is group work. The requirement is exactly the same as in Exercise 3, but now you will work in groups. Each group must adopt, adapt, or design from scratch,*

the most efficient system possible, or at least practical, in terms of using the fewest number of bits. Within each group you may share and discuss your individual group member' solutions for Exercise 3, and incorporate any part of any group member' solution in your response for Exercise 4. Your solution should include methods for dealing with collisions and for ensuring network fairness. Submit only one solution per group.

Exercise 4 finally tasks the students to strive for efficiency in their systems, and gives them a sample of what it might be like to work on a protocol development team. Teams have two weeks to complete their work. Students very frequently comment that the requirement to reach a group consensus and the inherent need to compromise within the group is by far the most challenging aspect of the Dark Room exercises. For Exercise 1, 2, and 3 they had no one but themselves to please and any written explanation of a solutions always made perfect sense to the author. Now they have a group to convince, and several peers critiquing anything they write to explain their system. Exercise 4 is made even more challenging by the international nature of our student body as each group will include at least one non-U.S. student. Language and experiential issues often arise and must be overcome.

Our definition of 'efficiency' is relatively simple and straight forward – use as few bits as possible to convey the message while ensuring messages get through to the intended receiver. Efficiency is easy to describe, and not too difficult to achieve, but students can spend a great deal of time arguing about the implementation details. Most groups will settle on a six bit encoding of the numbers to be transmitted and 3 bit addressing for the receiver, but they can still debate whether to transmit the message with the least significant bit (LSB) or most significant bit (MSB) leading. They can debate for-or-against using the unique sound signaling device to save two bits. They can debate whether to lead with the source or destination address.

We generally find that the teams argue most about how many bits to use, and how to use them, for collision avoidance and flow control. Are start-stop bits really necessary? How many, if any, bits should be used between message elements? Is it necessary for a station with no message to send to transmit anything to signal that they are not taking a turn? How many bits overall are really necessary to keep senders and receivers synchronized? How can fairness be ensured?

Experience, rather than a detailed mathematical analysis, tells us that a highly efficient and relatively effective and straight forward solution consists of:

- Enforce strict turn taking (stations 1 through 6 in order) for collision avoidance
- Allow only one destination per turn to ensure fairness.
- Have stations start and end each turn with their unique sound signal, including using two back-to-back unique sounds to indicate that a station has no message to send during that turn. The use of the unique sound also serves as the source address.
- Use three bit encoding for the destination address
- Use six bit encoding of each number to be transmitted
- If more than one number is to be transmitted to a single destination during a turn transmit additional six bit groups prior to terminating the turn with the second iteration of the unique sound.

This method results in an 11 bit basic message consisting of a 1 bit unique sound marking the start of the message and identifying the source; followed by a 3 bit destination address; followed by a six bit message; and concluded with a 1 bit end of message signal.

Example Student Solution for Exercise 4

1. *Bits will be transmitted one per second.*
2. *Seconds will be counted one-one-thousand, two-one-thousand, etc.*
3. *Each station must have a permanent unique address from 0 to 7.*
4. *Each station must know the addresses of the other stations.*
5. *Each station will take turns in order of station number to send a message.*
6. *When it is a station's turn they have two options:*
    a. *A sender can give up their turn by pressing the 2nd, "unique" sounding buzzer once.*
    b. *A sender can take their turn by pressing the 2nd, "unique" buzzer twice and then begin transmitting with the "regular" buzzer.*
7. *Once a sender has started transmitting the next station in line will have to wait 25 seconds (enough time for the 24 bits to be transmitted) before it becomes "their turn."*
8. *The next sender's turn begins exactly 1 second after the transmission completes or 1 second after the previous sender gives up their turn.*
9. *Each packet contains 24 bits. Consisting of a header (6 bits) and message (18 bits).*
10. *An 18 bit message immediately follows the header. This message is broken up into 3 numbers that are represented by 6 bits each.*
11. *Each number in both the header and message will be decoded using unsigned binary (no negative numbers).*

Each transmission is preceded by two buzzes from the unique station buzzers.

<u>Transmission #1</u>

Header = 011001 yields
Receiver = 011 = Station #3
Sender = 001= Station #1
Message = 000101011001101000 yields
<u>Number 1:</u> 000101 = "5"
<u>Number 2:</u> 011001 = "25"
<u>Number 3:</u> 101000 = "40"

Dark Room Exercise 5

This is the 5th and final Exercise and it is again group work. For Exercise 5 two groups will work together to form a new group. In this exercise, the data to be transmitted remains the same. Now, the task is to communicate between two separate dark rooms. Each group from Exercise 4 must exchange messages with the other group in the new teams. Any station in either room must be able to send a message to *any station in either room. Both the sender and the receiver must be identified in the message.*

NEW HARDWARE: There are two pairs of wires run between the two rooms. One end of each pair of wires is connected to station 1 in one room, and the other end of that pair is connected to a speaker in the other room --- in other words, the sounds coming from station 1 (and only station 1) in each dark room can be heard in the other dark room.

The systems should be efficient, but reliability is more important than efficiency. The memory of the operator of station 1 is pretty good, but not permanent --- he/she can only remember/store a message for 30 seconds. The room is still dark, so station 1 is not allowed to write messages down.

Remember that each station must still be able to send a message to someone in their room and be able to send to a station in the other room. Include an example of a message sending the number 35 staying in the room, and an example of a message sending the number 45 being sent to the other room. Turn in just 1 response for each pair of teams.

Exercise 5 continues the requirement to work in groups and achieve consensus among the new group, but now the number of people involved is doubled. Two previously separate teams must agree on common systems. Students are allowed two weeks for this exercise.

There are two new twists in this exercise. First, the use of a relay (think hub, bridge, or switch) as station 1 in each room is the only station that can transmit to the other room. Second, the relay has only a short duration ability to store a message before it must be forwarded to the other room. Failure to frequently give station 1 the opportunity to transmit to the other room will result in lost messages. The timing constraint of this relay requirement is generally cited by students as the toughest part of Exercise 5.

Additionally, this final exercise includes a new danger of collisions. The designed system must ensure that a message being relayed from one room to the other does not collide with a message in the destination room. This room-to-room collision issue is often overlooked by students and generally is the greatest cause of lost points on Exercise 5.

Sample Instructor's Solution

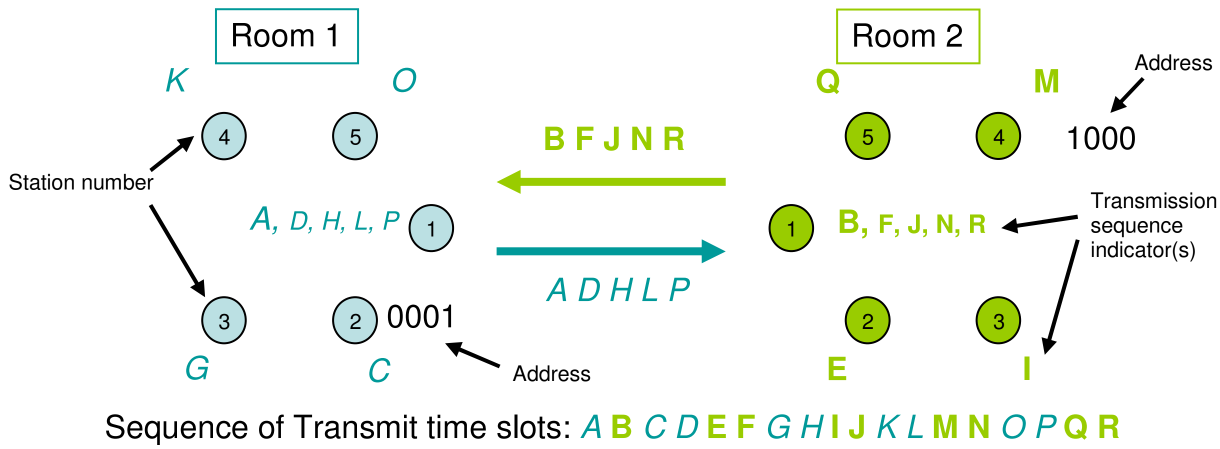
Each of the ten stations has a different unique sound buzzer (represented by "@" in the example message). Strictly ordered turn taking is use to avoid collisions and ensure fairness. Stations 2 to 4 in each room get 1 time slot. Station 1 in each room gets 5 time slots. Station 1 in each room uses its first time slot for its own message, and the other 4 slots to relay messages to the other room. 4 bit encoding of 10 unique addresses, 6 bit encoding of the message, 1 unique buzz to start and end each message. 12 total bits. (Represented by 0 or 1)

Message example: person/station #2 in room 1, sending the number one, to person/station #4 in room 2 = @1000000001@

Person/station #1 has to add the sender's address to the message, so #1 sends: @00011000000001@ to the other room

Each bit takes 1 second, so the total elapsed time for #1 to hear and retransmit a message is less than 30 seconds (12+16) so his volatile memory is OK.

Supporting Solution Diagram



Related Work

As stated earlier, literature reviews have not revealed documentation of similar concepts for the teaching of basic communications protocols. At our own university a similar 'dark room' environment has been used to teach system analysis and design techniques. Students are challenged to create a list of detailed and precise steps/instructions necessary to guide a blindfolded and disoriented subject to a light switch in a dark room. In their initial attempts, students generally fall far short of being explicit and complete enough leaving the test subject in the dark through many rewrites of the instructions.

On a much more serious note, there is a great deal of documentation about the use of clandestine 'tap codes' (Alexander, 2003) used by real-world prisoners to communicate between cells without the benefit of any other supporting infrastructure. These scenarios are made much more complex by the fact that in the most severe environments, prisoners do not get the opportunity to pass instructions to new prisoners who must learn to use the systems with no external help.

Conclusions

The fundamental conclusion of many semesters of experience in using evolving versions of the Dark Room Exercises is that they constitute an effective method of teaching the fundamental principles of communications protocols. This conclusion is supported anecdotally by student after-course surveys and test results. The Dark Room Exercises are especially relevant in preparing student to study communications protocols. When students begin to examine TCP/IP packets or ATM frames, they know from first hand experience what it is like to develop source and destination addresses and why synchronization bits are necessary. In general, students that have completed the Dark Room Exercises feel much more comfortable with interpreting protocol content diagrams.

Further, our experience over the past three years during which the exercises have been used as a key element of 'online' courses is that the Dark Room Exercises are a very good 'virtual lab' substitute for hands-on labs that are impractical for online courses.

Future Work

We are extremely interested in sharing ideas about our Dark Room Exercises with other institutions using similar techniques. We are hoping that publishing a description of the exercises will bring similar programs or publications to light.

In addition to refining and expanding the exercises over time, we hope to more formally collect more student feedback and develop and use formal assessment mechanisms. Survey instruments will be developed during the coming year and institutional approval for their use will be requested. After review and approval of the survey instruments and assessment mechanisms they will be implemented in future iterations of our TSM601 course.

Alexander, Paul, Man of the People, The Life of John McCain, John Wiley & Sons, Hoboken, 2003, p 60.