Implementing MACA and Other Useful Improvements to Amateur Packet Radio for Throughput and Capacity

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Steven Gunderson – CMoLR Project Manager

TAPR DCC – 15 Sept 2018

Contents

Background

- **Mission County – Proverbial**:
  - Coastline, Earthquake Faults, Mountains & Hills, and Missions
  - Frequent Natural Disasters
    - Wildfires, Earthquakes, Floods, Slides & Tsunamis
  - Extensive Packet Networks
    - EOCs – Fire & Police Stations – Hospitals
    - Legacy 1200 Baud Packet Networks
    - Outpost and Winlink 2000 Messaging Software

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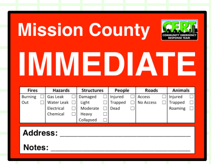
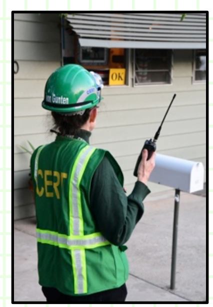
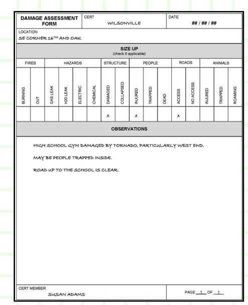
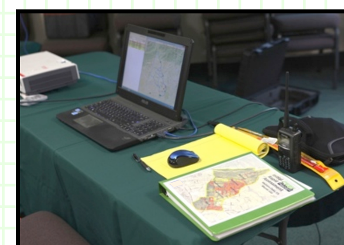
- **<u>Community Emergency Response Teams</u>:**
  - OK Drills
  - Neighborhood Surveys
  - Triage Information
    - CERT Form #1
  - Transmit CERT Triage Data to Public Safety – Situational Awareness









Background & Objectives (cont)

- **Communication Methodology of Last Resort (CMoLR):**
  - Mission County Project: 2012 – 2016
  - Enable Emergency **Data** Comms from CERT to Public Safety

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  - **Independent** – Data Communication System
    - Off the "Grid" – Phone, Cell, Cable & Internet
  - **Interoperable**
    - Amateur Radio and Land Mobile Radio (LMR) Radios
      - Analog and AX.25
  - **"Make It Work with What We Have"**
    - Urban Areas Security Initiative (UASI) Grant Radios

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  - **“Make It Work with What We Have”**
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- <u>**Preliminary Test / Demo**</u>**:**
  - Depiction Mapping Elements – Location + Properties
  - E-mail ➔ −Header ➔ XML ➔ APRS ➔ XML ➔ +Header ➔ E-mail
  - 1200 Baud – UNPROTO – 1 Packet – a Few Seconds

SPEED & THROUGHPUT TESTS

Speed & Throughput Tests – CONNECT

- **Winlink 2000 Reported Throughput:**

Winlink 2000 Binary - (4,000 bytes)	**Time** min	**Time** seconds	**Binary CPS** 4,000/seconds	**Ideal Speed** CPS	**Throughput** %
Packet (1200) direct	2	120	33	120	28%
Packet (1200) 1 node	2.5	150	27	120	22%
Packet (9600) direct	1	60	67 **2X**	960	7%

Frequently Asked Questions (FAQ) about Winlink 2000 – Q&A 170, https://www.winlink.org/sites/default/files/wl2k_faq_20150314.pdf, March 14, 2015.
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ftp://autoupdate.winlink.org/User%20Programs/wl2k_faq.pdf, February 28, 2018.

- **Outpost Measured Throughput:**

Outpost ASCII - (2,410 bytes)	**Time** sec	**ASCII CPS** 2,410/time	**Ideal Speed** CPS	**Throughput** %
Packet (1200) - KPC-9612 / Motorola	53	45	120	38%
Packet (9600) - KPC-9612 / Motorola	20	120 **2.7X**	960	12%

  - Connected Throughputs Were Less Than Ideal
  - 9600 Baud Did Not Provide Expected Several-Fold Increase
  - Frequent TX/RX Turn-Arounds – Exceeded Data Transfer Time

Speed & Throughput Tests – UNPROTO

- **1200 Baud CONNECT vs. UNPROTO Throughput:**

1200 Baud Mode	**PACLEN / Frame**	**File Size** cmpr (uncmp)	**Time** sec	**CPS**	**Ideal Speed** CPS	**Throughput** %
CONNECT - WL2K	128 / 4?	4,000 (binary)	120	33	120	28%
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UNPROTO	256 / 6	1,588 (2,410)	24	66	120	55%
UNPROTO	256 / 6	4,520 (7,959)	62	72	120 **2X**	60%
UNPROTO	256 / 19	4,520 (7,959)	57	82	120	68%
UNPROTO - Simplex	256 / 16	8,285 (22,495)	78	101	120	84% **3X**
UNPROTO - Analog Rptr	256 / 16	8,285 (22,495)	84	94	120	78%

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- Larger UNPROTO Packets and Longer Windows (Frames)
  - Improve Throughput Compared with CONNECT
  - 2X – 3X Overall
- Larger Packets Provides Greater Benefit Compared with Frame Size
- Settled on Default PACLEN of 256 and Frame Size of 16
  - Send 1 ACK per 4KB
- Simplex Throughput of 70-80% is Achievable

Speed & Throughput Tests – UNPROTO

- **9600 Baud CONNECT vs. UNPROTO Throughput:**

9600 Baud Mode	**PACLEN / Frame**	**File Size** bytes	**Time** sec	**CPS**	**Ideal Speed** CPS	**Throughput** %
CONNECT - WL2K	128 / 4?	4,000 (binary)	60	67	960	7%
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UNPROTO - KPC-9612	256 / 7	8,285 (22,495)	20	412	960 **6X**	43%
UNPROTO - KPC-9612	256 / 17	8,285 (22,495)	16	514	960 **7X**	53%
UNPROTO - KPC-9612	256 / 96	21,621 (77,745)	26	830	960	87% **12X**

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UNPROTO - KPC-9612	256 / 96	21,621 (77,745)	26	830	960		87%	**12X**
UNPROTO - Internal TNC Kenwood TM-D710G	256 / 96	21,621 (77,745)	36	600	960		62%	**9X**
UNPROTO - Internal TNC Kenwood TM-D710G	256 / 16	21,621 (77,745)	43	487	960		51%	**7X**
UNPROTO - Internal TNC Kenwood TM-D710G	256 / 128	21,621 (77,745)	37	566	960		59%	

- Larger UNPROTO Packets and Longer Windows (Frames)
  - Improve Throughput Compared with CONNECT
  - 7X – 12X Overall
- 9600 Baud Provided Expected Several-Fold Increase

UX.25 – UNPROTO AX.25

UNPROTO AX.25 – UX.25

- **Packet Design**:
  - **Follows APRS® Conventions** – Experimental APRS Packets
  - **AX.25 Unnumbered Frames (U) – Outer Wrapper**
    - **NO** Changes to AX.25 !!!
  - **UX.25 Rides Inside AX.25 Data Payload – Secondary Header**
    - **Appliqué** – Within AX.25

AX.25 Unnumbered Frame (U)					
Primary Header			**Payload**	Error Detection	
Flag	Address	Control	Info	FCS	Flag

Small Headers
- Minimize Impact
- 6 Bytes Maximum
- Including: Identifier
  Close
- 250 Byte Payload

UX.25 Command		
Flag	Data	Close

UX.25 Message					
Secondary Header				Payload	
Flag	Addressing	Sequence #	Type	Data	Close

UX.25 File Transfer					
Secondary Header				Payload	
Flag	Start	Sequence #	Type	Data	Close

UX.25 (cont)

- **Command:**
  - **Similar to APRS® Packets** – Simple Commands Plus Data

UX.25 Command		
Flag	Data	Close

  - **Broadcast Packets**

Command	Description
CQ?	Who's My Repeater?
SH	I'm Your Smart Host, e.g. Digipeater
CALLSIGN	My Call Sign
GPS	Coordinates
TIME	GMT, etc.

  - **Directed Packets**

Command	Description
BROADCAST	Broadcast Request for Repeater
CALLSIGNS	My Call Sign + Call Signs Heard
CERT	Address + Damage Assessment
MAP	KML, KMZ, SHP

UX.25 (cont)

- **<u>Message</u>:**
  - **Secondary Header** – Addressing, Sequence & Type

UX.25 Message						
Secondary Header					Payload	
Identifier	Addressing (optional)		Q	Command	Data	Close
	Source	Destination	Unsequenced			

Identifier	Addressing		Q	Type	Data	Close
	Source	Destination	Sequence #	Plain Text / Encoded		

Command	Description
SYN	Sync, i.e. Login
ACK	Login: +seq or OK, Data: +seq
NAK	Login, Unknown User, Bad Passwd, File Too Large, Data: +seq-seq-seq
SY / SN	Send Yes: Packets, Zip Size, Orig Size
DAT	Data
EOF	End-of-file
CLO	Close

UX.25 (cont)

- **Sync (SYN) Packet:**
  - **Core to File Transfer** – Combines Multiple Functions
  - Avoids Lengthy Session Protocol Exchanges
  - Follows Unix-to-Unix Copy (UUCP) Conventions

```
     Login        Passwrd    SN       Job Name     Org File Name  Cmd   Pkts  Zip Org  Jobs  Notify
user@domain.net|LetMeIn|sernum|1309D100502000|TestData2.txt|uucp|  4  |706|956|  0  |notify|
       1            2       3          4              5          6     7    8   9    10     11
```

Field #	Description	Authentication	UUCP	Packet
1	Remote Account Login	X		
2	Remote Password	X		
3	Remote Serial Number	X		
4	Job Name		X	
5	Original File Name		X	
6	Job Command		X	
7	Expected Packets			X
8	Compressed File Size (bytes)			X
9	Original File Size (bytes)			X
10	Expected Jobs		X	
11	Notify		X	

UX.25 (cont)

- **File Transfer:**
  - Follows Sync (SYN) and Send Yes (SY) Message Packets

```
   1        2        3      250              ' ChrB(2),  STX   Ctrl-B  Start of a Text
[-------][-------][-------](Data)[-------]   ' ChrB(3),  ETX   Ctrl-C  Returns to Command Mode
 Start    Seq 1    Type           End        ' ChrB(4),  EOT   Ctrl-D  End of a Text/Packet
ChrB(7)                         ChrB(4)      ' ChrB(7),  BEL   Ctrl-G  Start of a Packet
 <PKT>      0        0     Data   <EOT>      ' ChrB(13), CR    Ctrl-M  Carriage Return

 ChrB(7) + IntToChrId(seq) + IntToAxSeq(type) + Data + ChrB(4) + ChrB(13)

Seq:  0-35344 (188*188)

Type: 0      SYN Login/Sync Packet: Login Password SN Job File Expctpkts Cmprlen Origlen
      10-49  DAT Packet: 10 Sender Pausing for ACKs/NAKs, 11-24 Expect More Data Pkts
      150    DAT EOF packet
      170    NAK Login, Unknown User, Bad Password, File Too Large
      171    NAK Packet Data: +seq-seq-seq  Where + is an ACK, - is a NAK
      172    NAK File, Corrupt File Data
      180    ACK Login: +seq or OK
      181    ACK Packet, Data: +seq
      182    ACK File
      188    CLO Packet

Data: Can be up to 250 Characters, at 251 Characters the TNC Rolls Another Packet

EOT:  Char(4) and Char(13) if Packet Less than 255
```

MULTIPLE ACCESS WITH COLLISION AVOIDANCE (MACA)

Media Access Control

- **Amateur Packet Radio**:
  - ALOHAnet
  - Carrier Sense Multiple Access (CSMA)
    - Stations Listen for Transmissions – Carrier Sense (CS)
    - Wait for Predetermined or Random Times Following Transmissions
    - Stations Decide When They Transmit
  - Stations Try to be Polite and Not Interrupt Other Stations

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- **Hidden & Exposed Terminals**:
  - CSMA Works When All Stations Can Hear Each Other
    - Blockage and Distance Can Preclude Stations Monitoring Traffic
    - Stations May Transmit When Others Are Transmitting
    - Stations May Not Transmit When OK

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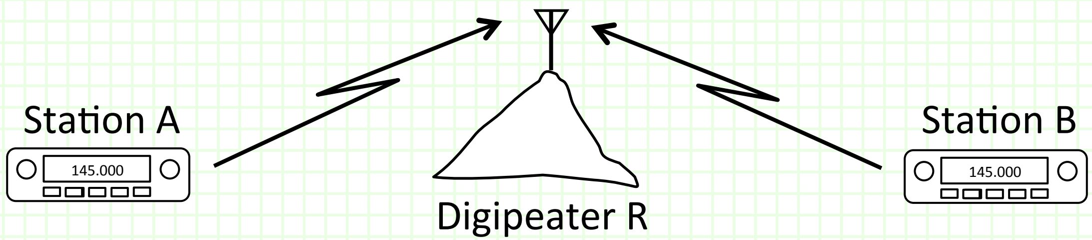
    - Stations May Not Transmit When OK
- **<u>Multiple Access with Collision Avoidance (MACA)</u>:**
  - Proposed – 9th ARRL Computer Networking Conference

Media Access Control (cont)

- **<u>Hidden Terminals</u>:**
  - Station (A) Can't Hear Station (B) and Vice Versa – Blocked by Hill
  - Both Stations Talk to Digipeater (R) at Same Time



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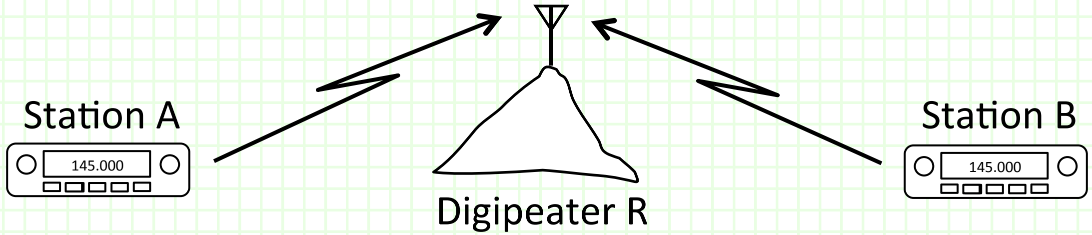
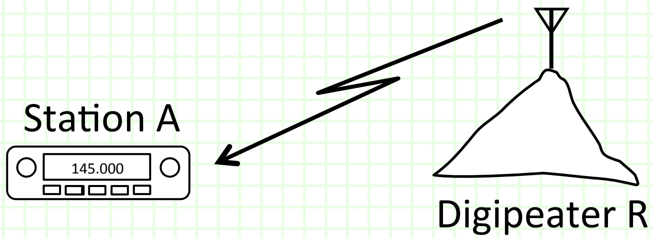


- **<u>Exposed Terminal</u>:**
  - Digipeater (R) is Talking to Station (A)



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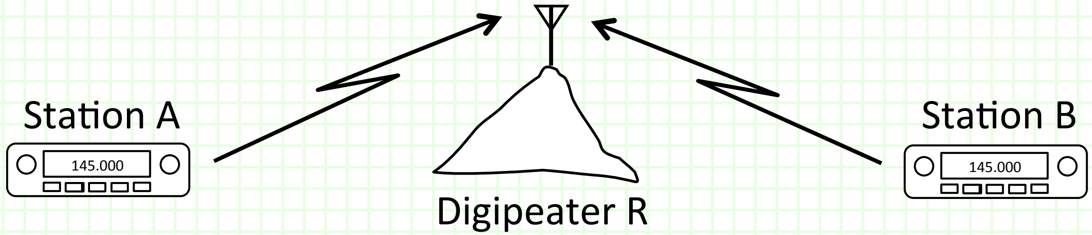

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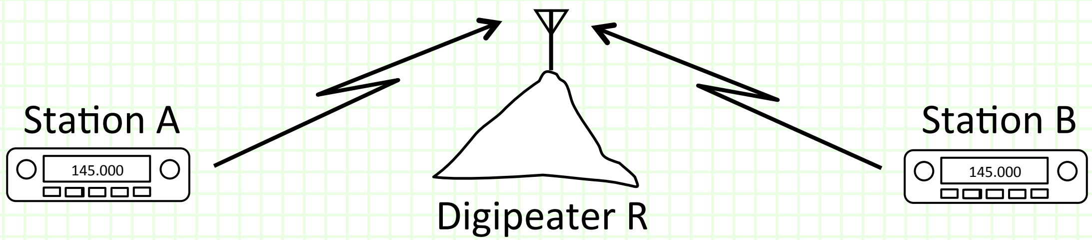
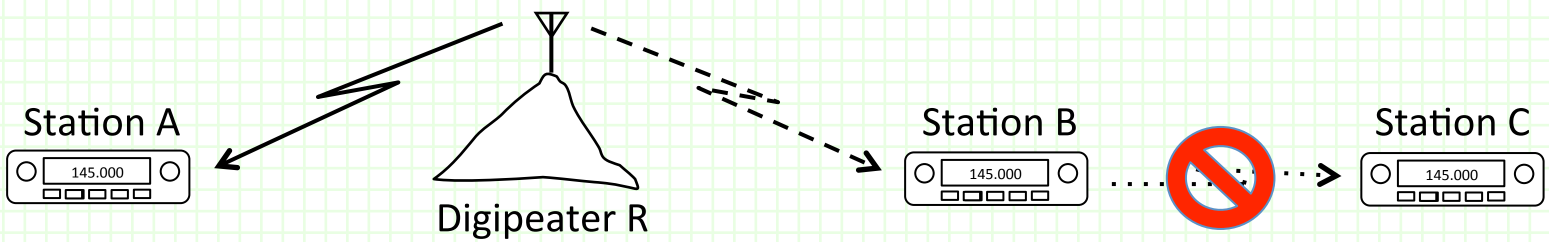
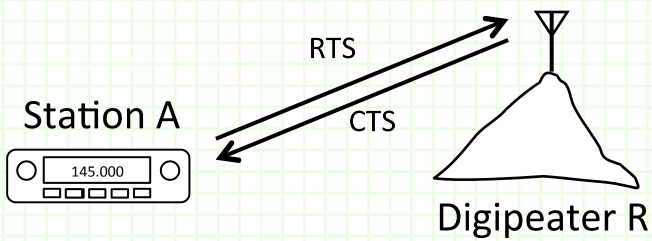


- **Exposed Terminal**:
  - Digipeater (R) is Talking to Station (A)
  - Station (B) Wants to Talk to Station (C) – Its OK – (A) is Out of Range
  - Station (B) Thinks Channel is Busy – It Doesn't Transmit



Media Access Control (cont)

- **<u>Multiple Access with Collision Avoidance (MACA)</u>:**
  - **Channel Pilots**
    - Request to Send (RTS)
    - Clear To Send (CTS)
    - Digipeaters Control Transmissions



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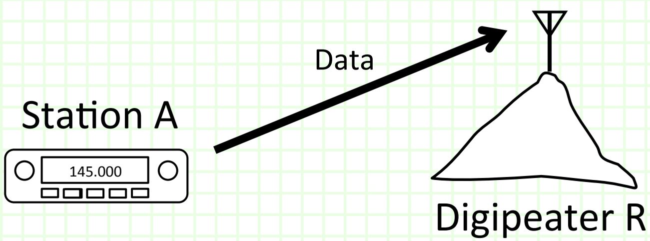

- Station (A) Sends a File to Digipeater (R) – After RTS/CTS

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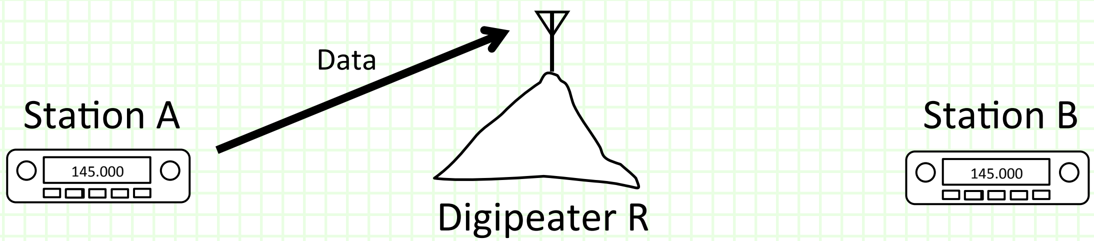

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- Station (B) Comes on Air and Does Not Hear Station (A)

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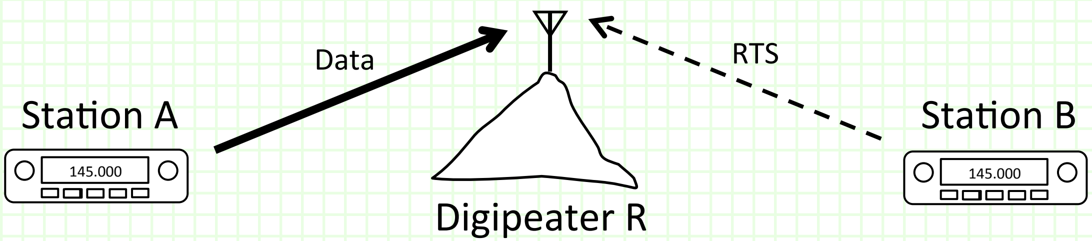

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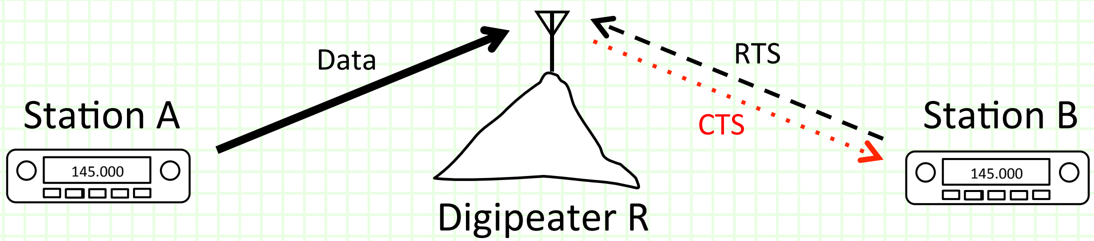

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    - Station (B) Sends RTS to Digipeater (R)
    - Digipeater (R) Does Not Respond to Station (B) RTS with CTS
      - RTS May Result in Station (A) Lost Packet

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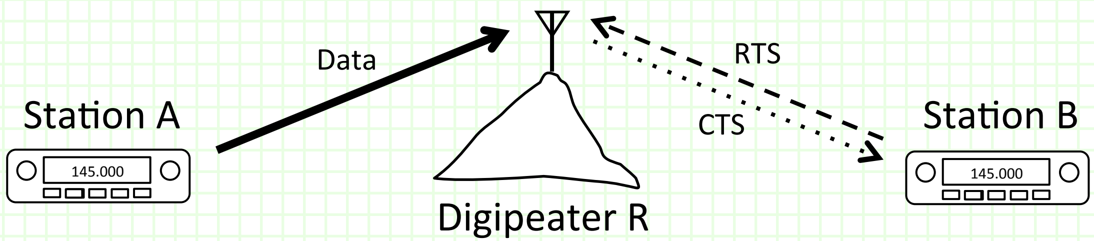

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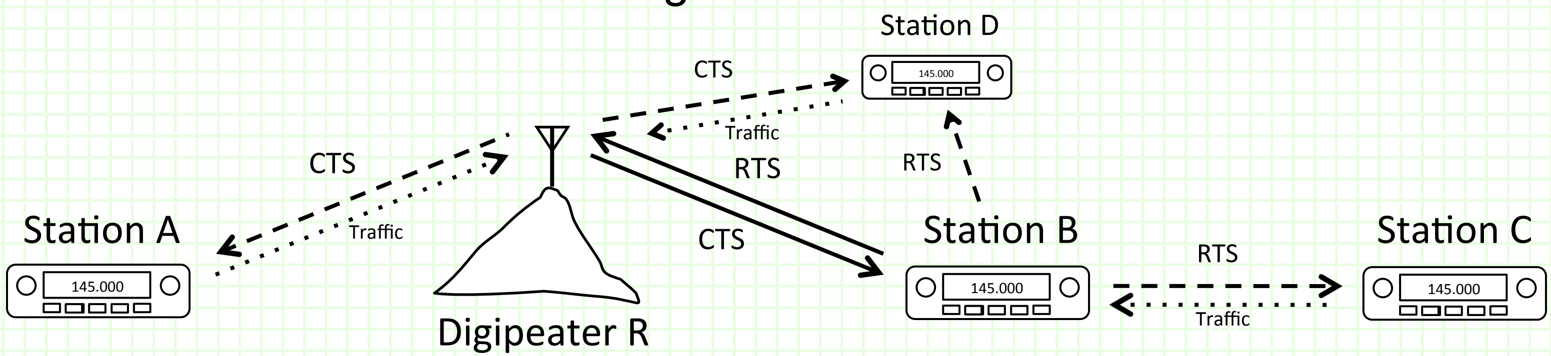
- Station (B) Comes on Air and Does Not Hear Station (A)
- Station (B) Sends RTS to Digipeater (R)
- Digipeater (R) Does Not Respond to Station (B) RTS with CTS
  - RTS May Result in Station (A) Lost Packet
- Station (B) Waits Until CTS is Received

Media Access Control (cont)

- **<u>Multiple Access with Collision Avoidance (MACA)</u>:**
  - **Overheard Conversations**
    - Stations Overhearing RTS/CTS Exchanges Know to Keep Silent
    - File Size Clues How Long



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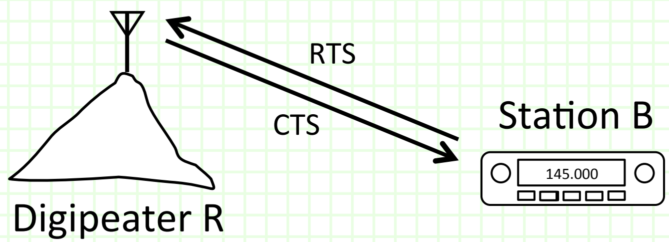

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Media Access Control (cont)

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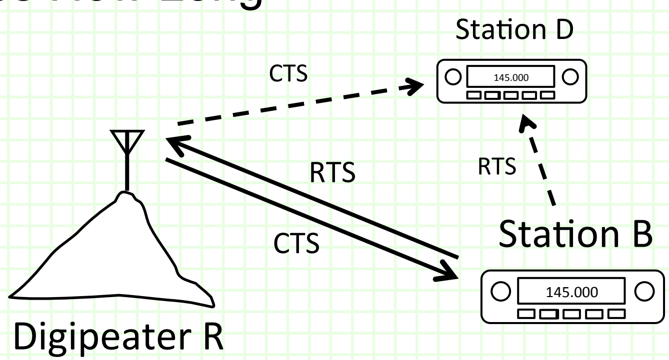

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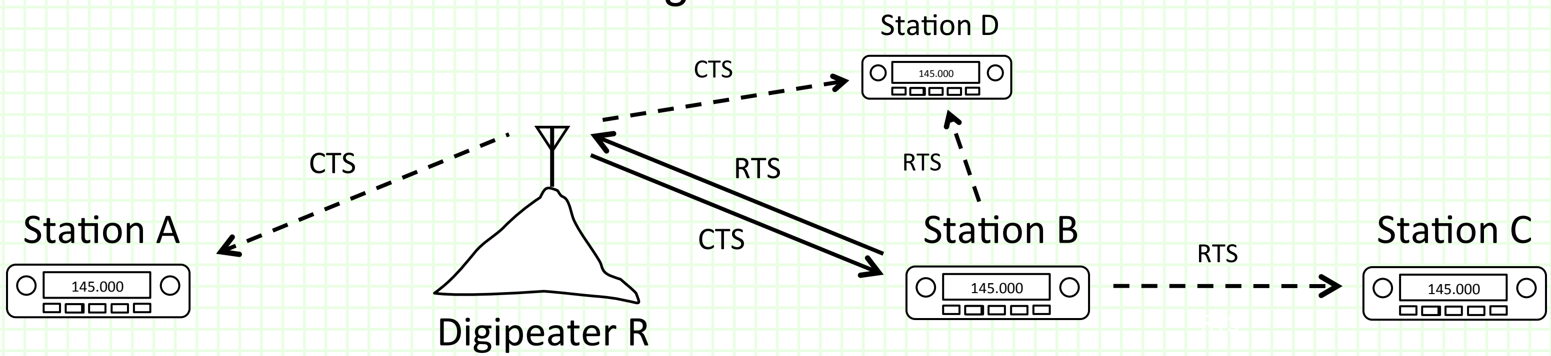

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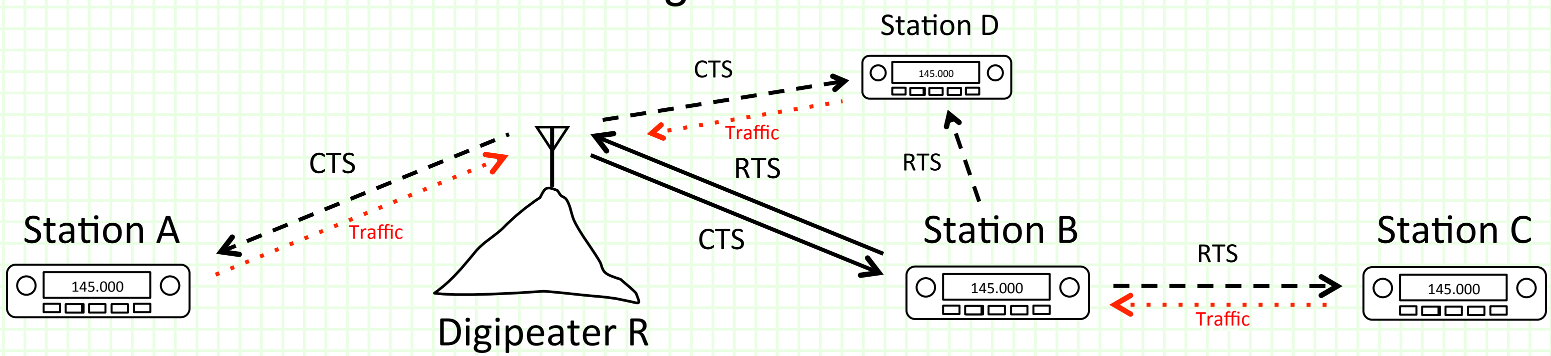

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    - Stations (A), (C) & (D) Wait Until Negotiated Transfers are Complete

Media Access Control (cont)

- **<u>MACA / UX.25 Equivalence</u>:**

Protocol	Request	Proceed	Don’t Proceed	File Size	Estimate Packets
MACA	Request to Send (RTS)	Clear to Send (CTS)	—	X	—
UX.25	Sync / Login (SYN)	Send Yes (SY)	Send No (SN)	X	X

  - Transmit Time Estimate
    - MACA – RTS/CTS – File Size
    - UX.25 – SYN/SY – File Sizes and Estimate Packets
      - CTS and SY Repeat Sizes for Stations That Do Not Hear Initial RTS/SYN
  - RTS/CTS and SYN/SY are Used for Multi-Packet File Transfers
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- **UX.25 Includes MACA Functionality**:
  - Monitor Other Station's Handshakes **– UNPROTO**
    - Not Dependent Upon Carrier Sense (CS)

OTHER USEFUL IMPROVEMENTS

Directed Packet Networks

- <u>**CSMA's Limitations**</u>**:**
  - <u>Stations Decide When They Transmit</u>
    - Works Well for Lightly Loaded Open Networks – e.g. APRS
      - Single Packet Transmissions
    - Does Not Work Well for Heavily Loaded Networks
      - Mixed Traffic – Short & Long
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- **Directed (Voice) Networks**:
  - Radio Amateurs Solved These Problems for Voice Nets
    - Scripts are Sophisticated Media Access Control (MAC)
      - Check In – (CQ)
      - Identify Traffic – (Urgent, Priority, Routine)
      - Network Control Either Grants or Doesn't Grant Permission
    - Short Breaks
      - Allow Stations to "Break the Net" with Priority/Urgent Traffic

Directed Packet Networks (cont)

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- **Digipeater Limits**:
  - Station-to-Station Simplex Without Relaying Through Digipeaters
    - RTS/CTS Clue Simplex Stations When “The Coast is Clear”
  - Short Single-Packet Commands & Messages
    - 9600 Baud – 250 Bytes < 1/2 Second – 1 KB Messages < 2 Seconds

Brevity

- **Increase Throughput:**
  - All Traffic is Urgent or Priority
    - Human Nature
  - Message Size is Natural Way to Prioritize Traffic
    - Encourage Network Etiquette
  - Reliable Short Message Transmission – UX.25
    - CONNECT and E-mail are Not Necessary for Reliable Transmission

Emergency Alert
FAST MOVING BRUSH FIRE
BETWEEN SANTA PAULA,
VENTURA, OJAI – GO TO:
READYVENTURACOUNTY.ORG

14 Words – 101 Characters

- **Proposed Grades & Sizes:**

Grade	Message	E-mail Files	Packets Max	Size	Comment
Emergency	X		1	250 Bytes	Similar to Text Messages
Urgent	X		2	500 Bytes	Similar to Text Messages
Priority	X		4	1 KBytes	Bridges Gap with E-mail
Routine		X	Multiple	10+ KBytes	E-mail is Always Routine

Brevity (cont)

- **<u>E-Mail</u>:**
  - Two-Part Addressing – user@domain
  - E-mail is Inefficient for Short Messages
    - Headers Can Add Hundreds of Bytes of Overhead

Brevity (cont)

- **E-Mail**:
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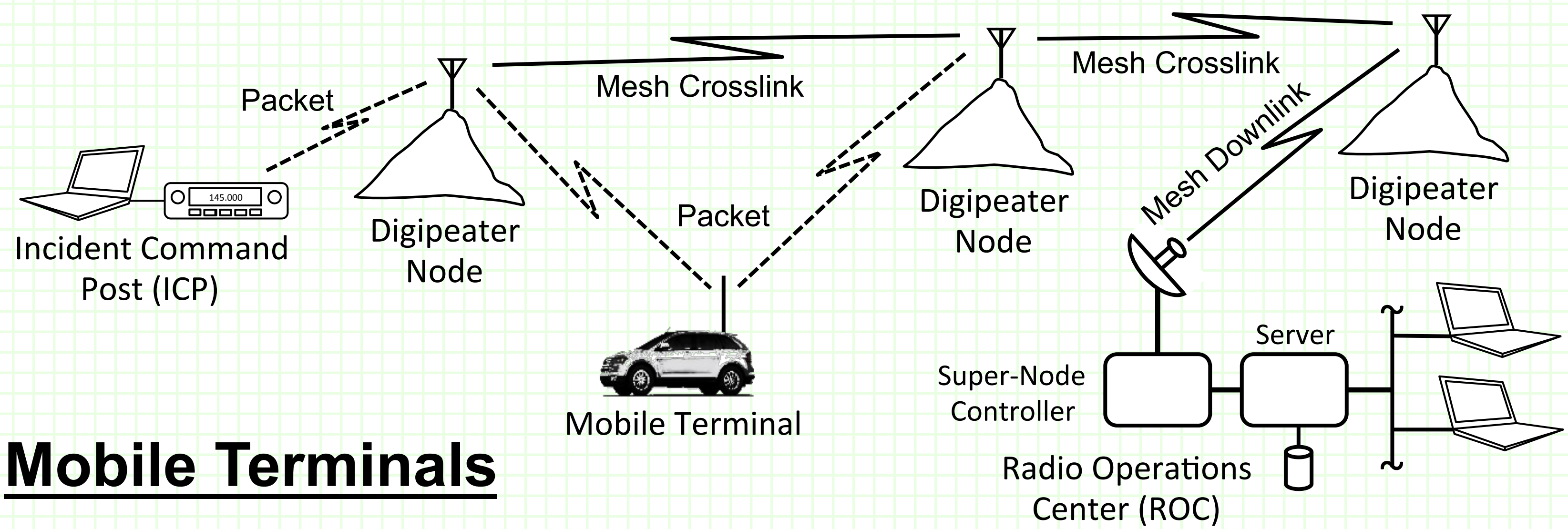
- **Directory Services**:
  - Message Addresses
    - Two-Part Addressing – user@domain – Without High E-mail Overhead
  - Secondary Source & Destination Addresses
    - Two Byte Addresses in UX.25 Message Header
      - Call Signs, Domain Names, Individual Accounts & Groups
  - Digipeater & Super-Node Controllers Host Directory Services
    - Stations Register With and Join Networks to Participate in Directories
      - Stations Send Their Domain & Local Accounts After Checking In
      - Digipeater Nodes and Servers Maintain Common Directory and Distribute
  - Makes Packet Networks Easier to Use

Trunked Packet

- **<u>Mobile Network</u>:**
  - Multiple Digipeaters
    - Last 10-Mile Comms
    - Fixed & Mobile Terminals
  - Fast Trunks – e.g. Mesh
    - Inter-Digipeater Communication and Coordination



- **<u>Mobile Terminals</u>**
  - Automatic Handoff Between Digipeaters

Trunked Packet (cont)

- **<u>Station / Digipeater Handshake</u>:**
  - Stations Check-In (CQ?) with Digipeaters
  - Digipeaters & Super Node Send “I’m Your Smart Host” (SH)
- **<u>Super-Node / Digipeater / Station Interaction</u>:**
  - <u>Messages</u> Forwarded to Closest Digipeater
  - Digipeaters Coordinate with Individual Stations Using MACA
  - **Network Handoff** – Mobile Stations
    - Digipeaters Forwarded <u>Messages</u> as Stations Move
- **<u>Message vs Packet Level</u>:**
  - Message Batching and Compression – Increased Throughput
    - E-mail & Short <u>Messages</u> – Multi-Addresses – Inside & Outside Network
- **<u>Independent of External Internet Servers</u>:**
  - Super-Nodes Fully Capable Smart Hosts

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  - Mobile Terminals – Automatic Handoff

Conclusion (cont)

- **<u>Multiple Access with Collision Avoidance (MACA)</u>:**
  - Originally Proposed for Single-Frequency Amateur Packet Radio Networks. It was hoped:

    "…it may *finally* make single frequency amateur packet radio networks practical."

    "…The ability to create usable, ad-hoc, single frequency networks could be very useful in certain situations…"

    "…This would be especially useful for emergency situations in remote areas without dedicated packet facilities."

Phil Karn (KA9Q), "MACA – A New Channel Access Method for Packet Radio"
Proceedings of the 9th ARRL Computer Networking Conference, London, Ontario, Canada, 1990

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