Fusion from the Inside

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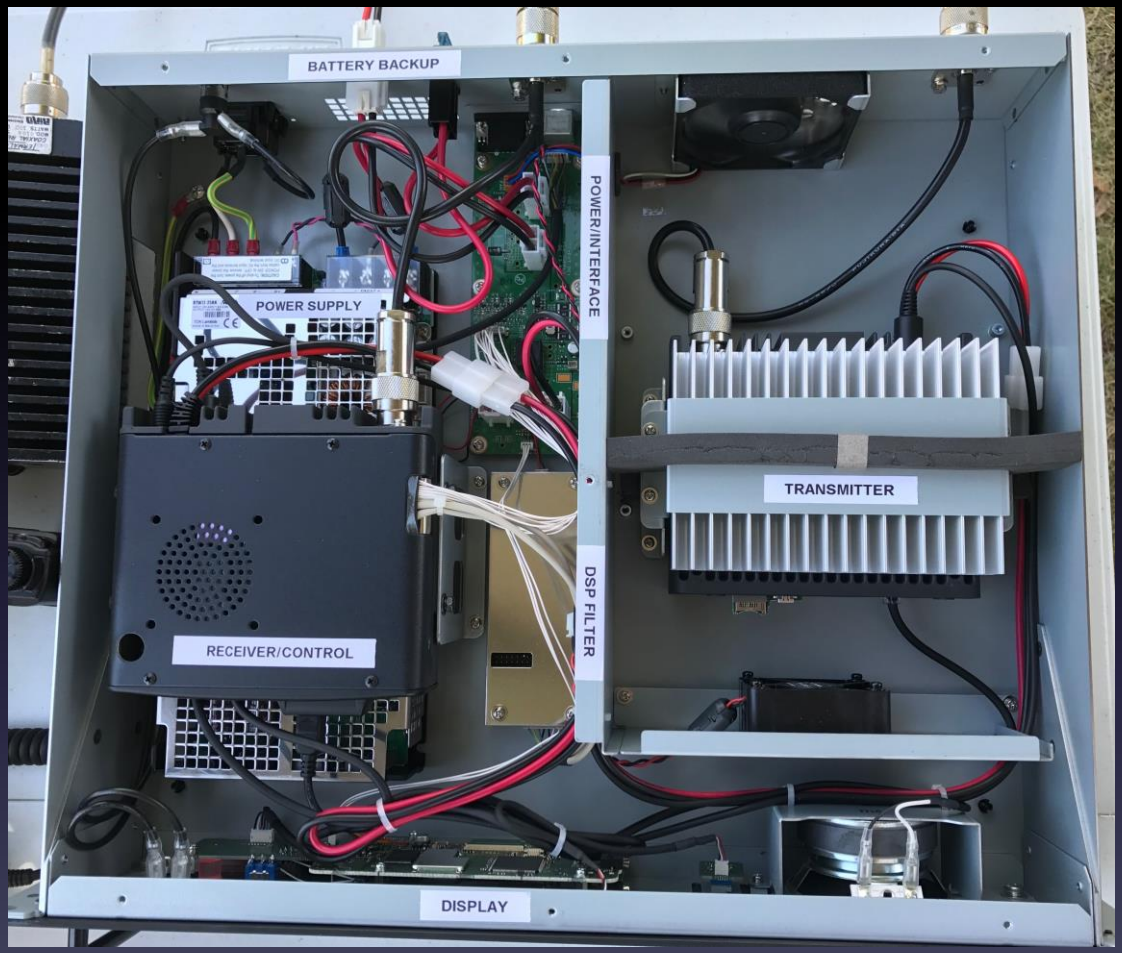
TAPR DCC September 15, 2017

Fusion from the Inside Abstract

- System design
- Broad examination of System Fusion and WiRES-X components
- What the components do and how they interact
- Public information
- Reverse Engineering
- Hams – How we can build on System Fusion for the future

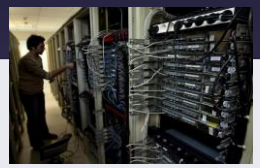


Fusion System Design

- Fit current FM spectral mask
  - Transition from FM to digital
- Use established standards – P25/C4FM
  - And modify for Amateur Radio
- User, Access Point, and Network layers

Fusion Subsystems

- Fusion / C4FM (Built on P25)
  - RF segment
- WiRES-X (Built on WiRES and WiRES II)
  - Networking segment
  - Nodes (Access Point)
    - Simplex access or remote repeater access
  - Repeaters (Access Point)



Network (Internet, RF)

Gateways (WiRES-X, DR-1/2)

Users (FT1/2/70, FTM-100/400/3200/3207, FT-991)

Popularity of Digital Voice

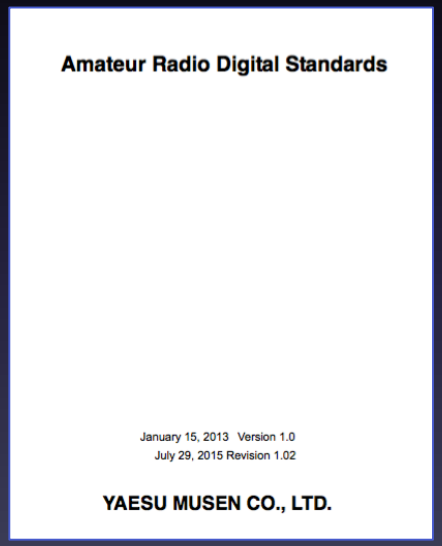
Mode	NA	World	MN	WI	IA	IL
Fusion	1,531	1,796	45	34	28	71
Dstar	1,137	2,174	31	27	7	31
DMR	1,189	1,994	22	28	9	45
P25	254	278	2	7	5	21
NXDN	93	93	2	2	3	3

Data from RepeaterBook.com retrieved 13-Sep-2017
Fusion may support FM and digital to various degrees

Fusion Subsystem

Published Standard

Amateur Radio Digital Standards



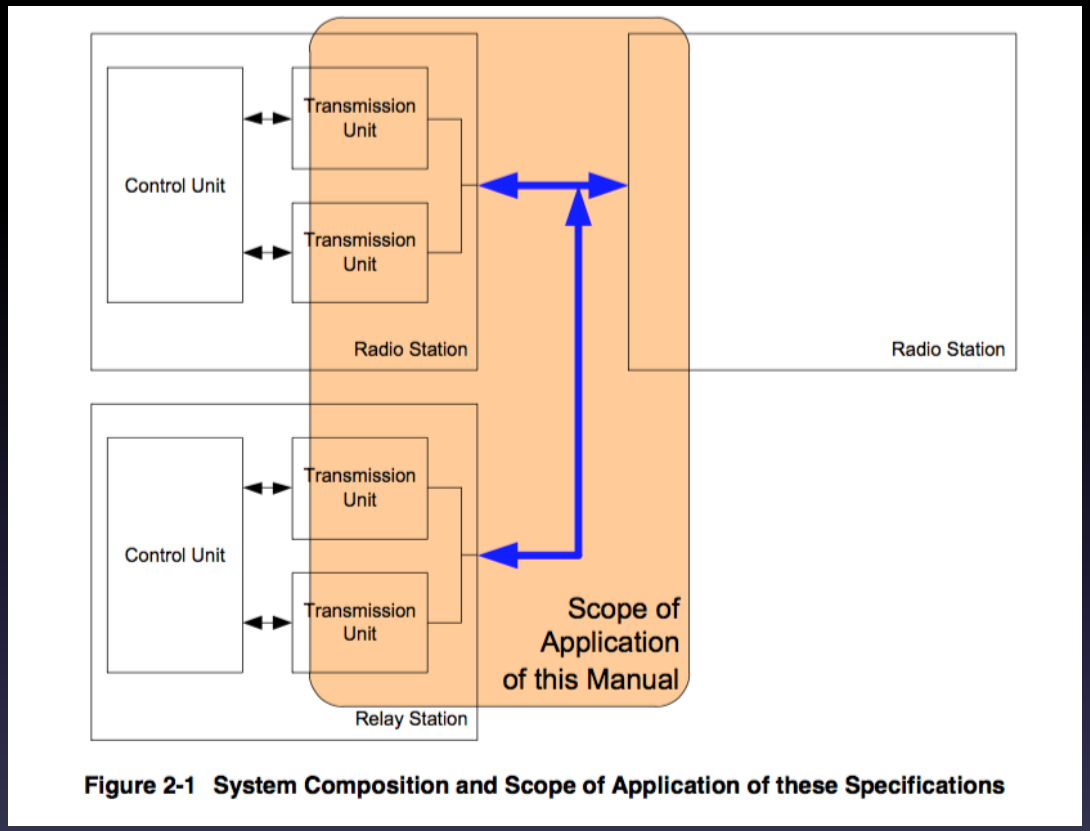


Figure 2-1 System Composition and Scope of Application of these Specifications

OTA Modes and Bandwidth

Four modes of operation:

Mode	Voice	FEC	Data
DN1	2,450	1,150	3,600
DN2	2,450	1,150 + 1,800	1,800
VW	4,400	2,800	
DW	7,200		

Table 3-1 C4FM Mapping

Dibit	Symbol	Frequency Deviations(Wide)	Frequency Deviations(Narrow)
00	+1	+900 Hz	+450 Hz
01	+3	+2700 Hz	+1350 Hz
10	-1	-900 Hz	-450 Hz
11	-3	-2700 Hz	-1350 Hz

OTA Protocol DN Modes

Frame

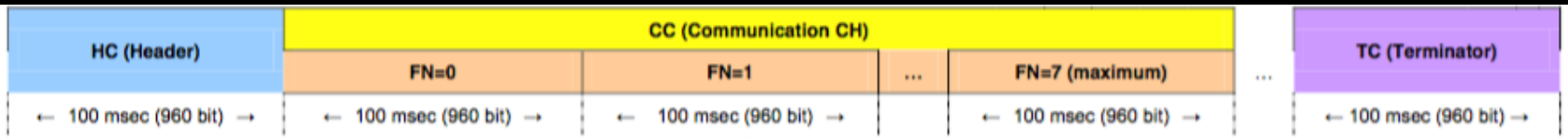


Figure 4-6 Frame Composition Drawing

DN1 3,600bps Data

FS	FICH	DCH (0)	VCH (0)	DCH (1)	VCH (1)	DCH (2)	VCH (2)	DCH (3)	VCH (3)	DCH (4)	VCH (4)	Number of bits
40	200	72	72	72	72	72	72	72	72	72	72	Total 960 bit

Figure -8 CC Structural Drawing

DN2 1,800bps Data

FS	FICH	DCH (0)	VCH (0)	VeCH (0)	DCH (1)	VCH (1)	VeCH (1)	DCH (2)	VCH (2)	VeCH (2)	DCH (3)	VCH (3)	VeCH (3)	DCH (4)	VCH (4)	VeCH (4)	Number of bits
40	200	40	72	32	40	72	32	40	72	32	40	72	32	40	72	32	Total 960 bit

Figure 4-12 CC Structural Drawing

OTA Protocol VW and DW

VW

The structural drawing of the CC0 (Sub Header CH) actual voice and superimposed data is shown in **Figure 4-21**.

FS	FICH	DCH (0)	DCH (1)	DCH (2)	DCH (3)	DCH (4)	Reserved	VCH (3)	VCH (4)	
40	200	72	72	72	72	72	72	144	144	Number of bits
										Total 960 bit

Figure 4-21 CC0 Structural Drawing

The structural drawing of the CC actual voice is shown in **Figure 4-22**.

FS	FICH	VCH (0)	VCH (1)	VCH (2)	VCH (3)	VCH (4)	
40	200	144	144	144	144	144	Number of bits
							Total 960 bit

Figure 4-22 CC Structural Drawing

DW

FS	FICH	DCH-1(0)	DCH-2(0)	DCH-1(1)	DCH-2(1)	DCH-1(2)	DCH-2(2)	DCH-1(3)	DCH-2(3)	DCH-1(4)	DCH-2(4)	
40	200	72	72	72	72	72	72	72	72	72	72	Number of bits
												Total 960 bit

Figure 4-15 CC Structural Drawing

Note: No FEC on data and no ARQ

Examine OTA Data

- Use a receiver to demodulate data
- Use software to process the signal
- Example
  - DV4mini
  - DV4RX – Github G4KLX/DV4RX
  - Build with VS 2017 Community

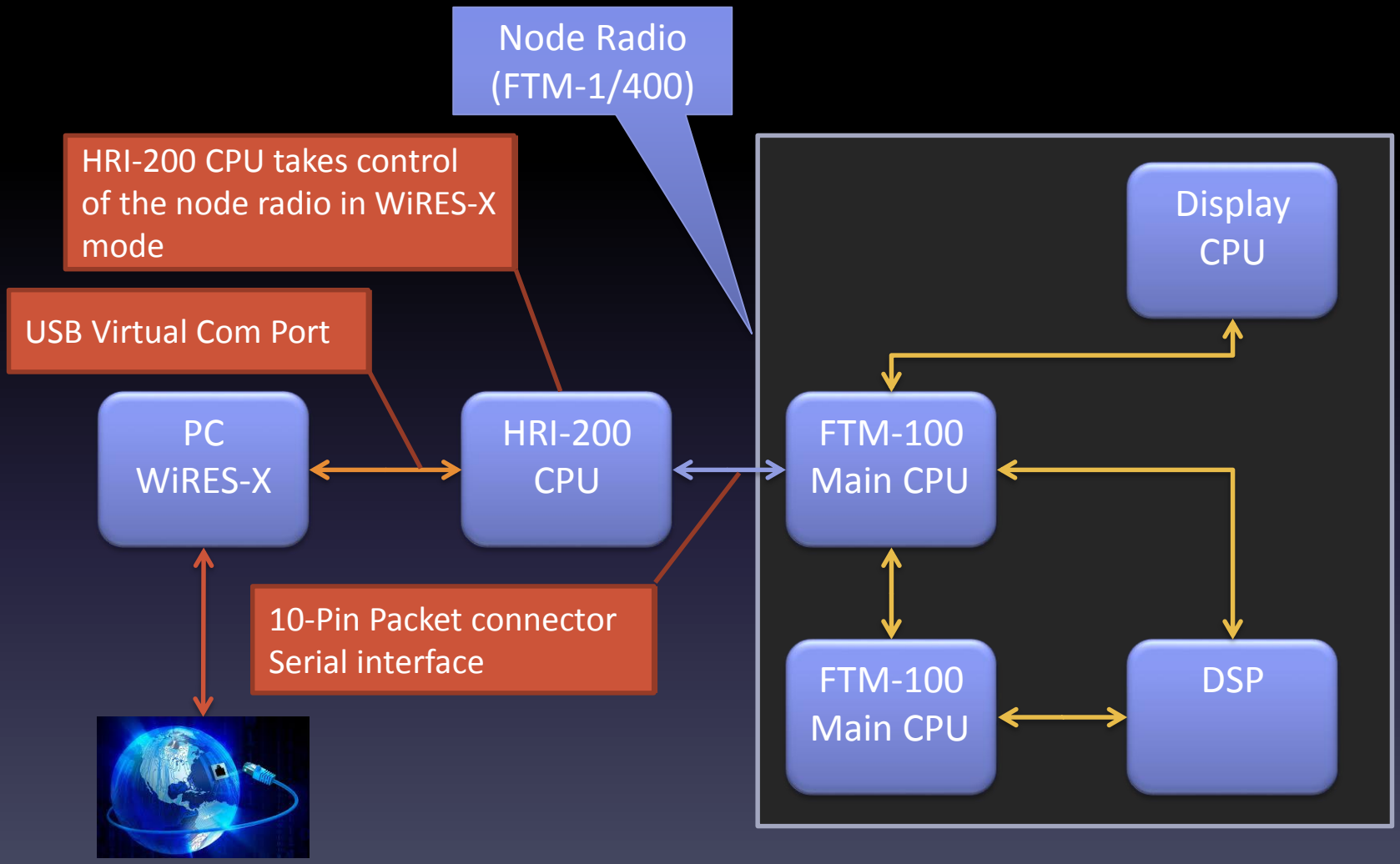
WiRES-X

Node

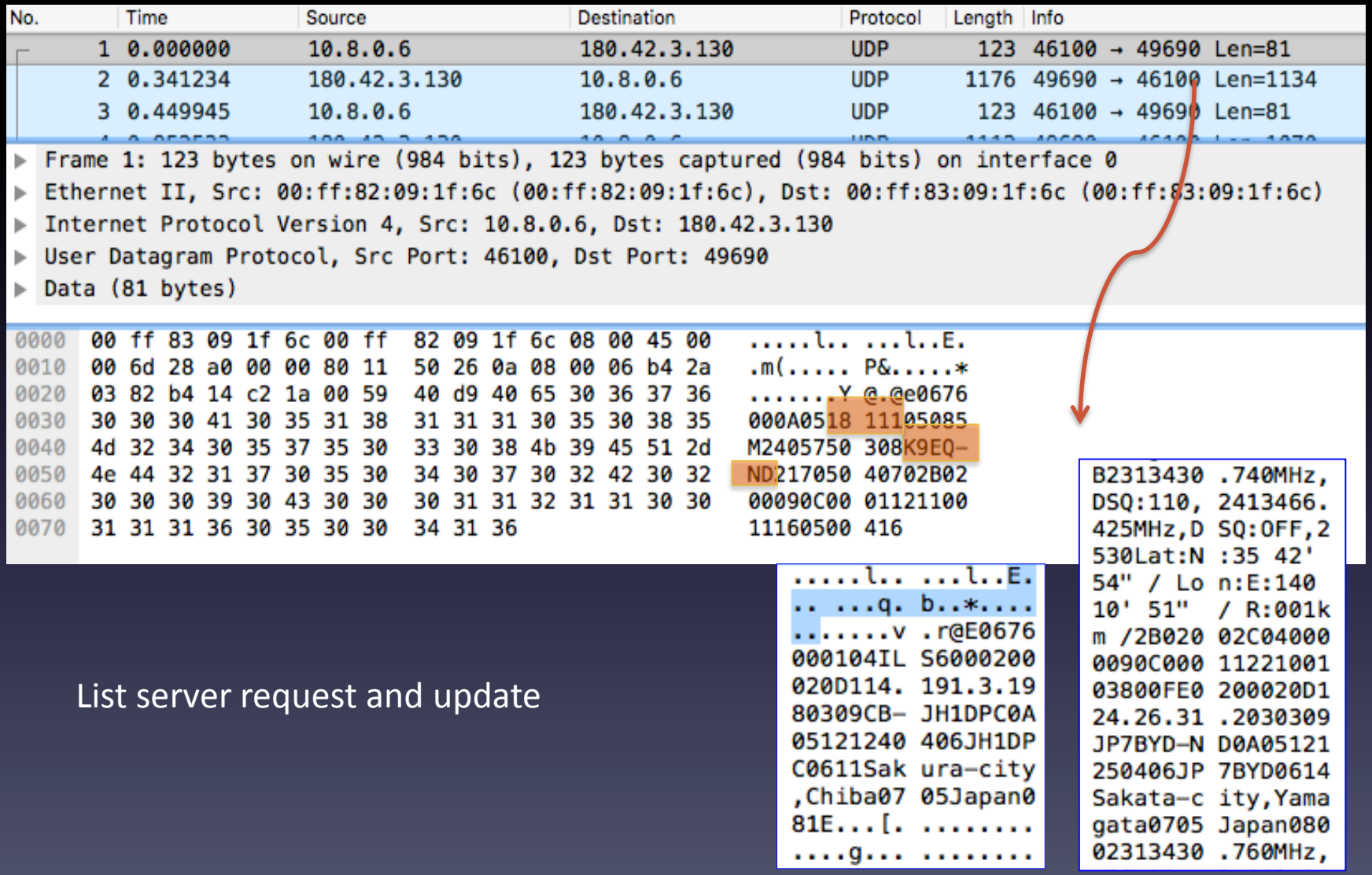
Room / Reflector

Yaesu List Server

WiRES-X Node Interface

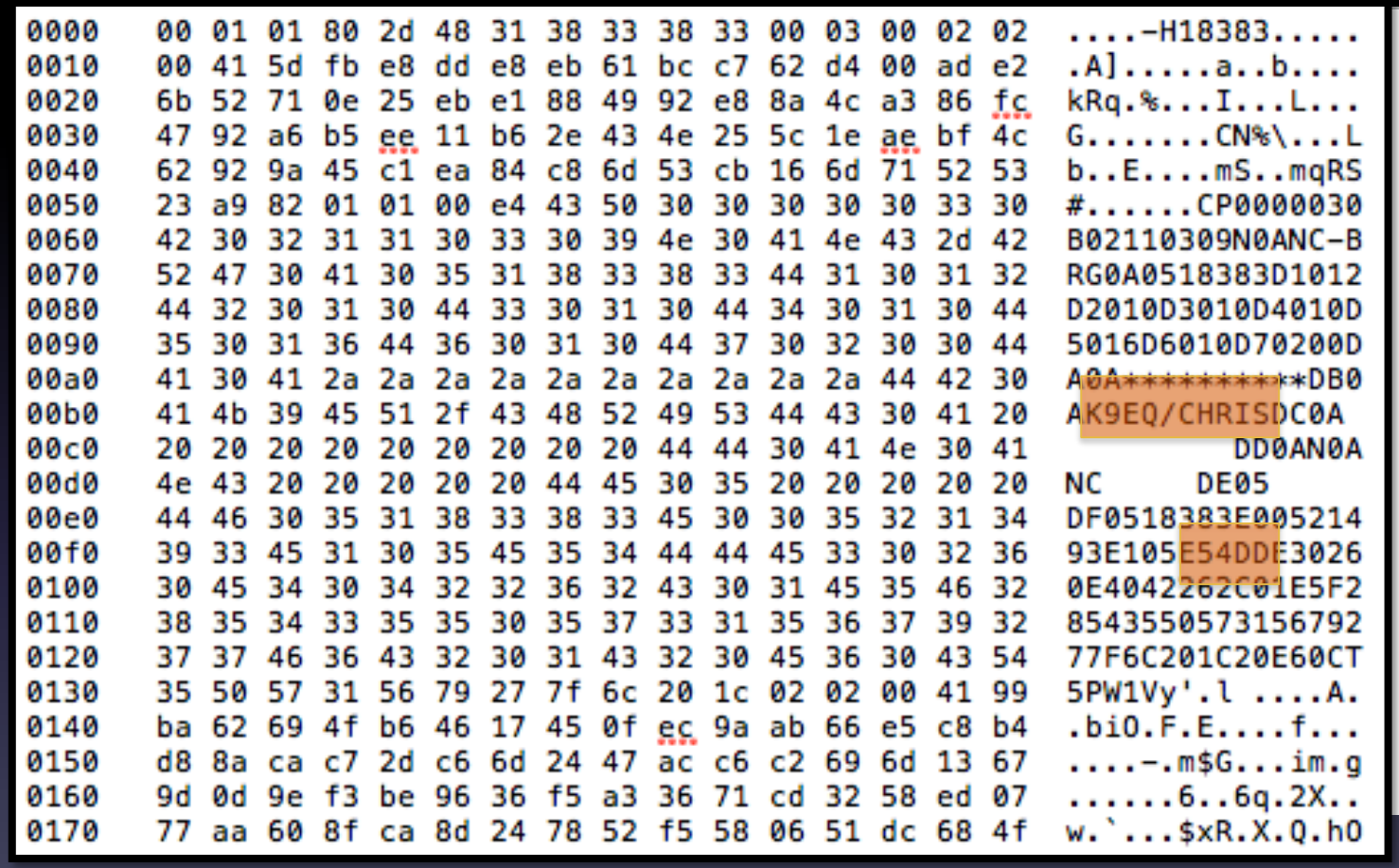


WireShark Network Captures



List server request and update

Capture: DMR Not Working



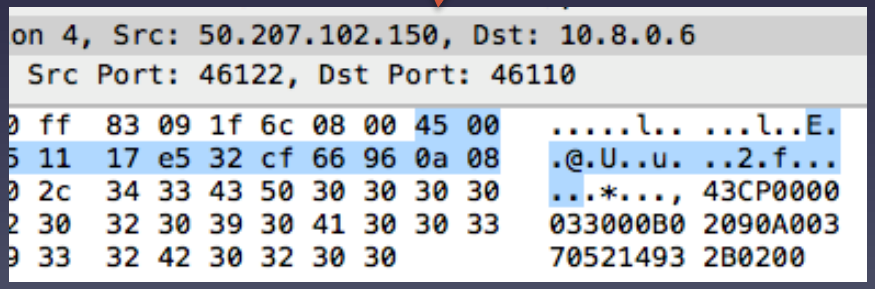
```
0000   00 01 01 80 2d 48 31 38 33 38 33 00 03 00 02 02   ....-H18383.....
0010   00 41 5d fb e8 dd e8 eb 61 bc c7 62 d4 00 ad e2   .A].....a..b....
0020   6b 52 71 0e 25 eb e1 88 49 92 e8 8a 4c a3 86 fc   kRq.%...I...L...
0030   47 92 a6 b5 ee 11 b6 2e 43 4e 25 5c 1e ae bf 4c   G.......CN%\...L
0040   62 92 9a 45 c1 ea 84 c8 6d 53 cb 16 6d 71 52 53   b..E....mS..mqRS
0050   23 a9 82 01 01 00 e4 43 50 30 30 30 30 30 33 30   #......CP0000030
0060   42 30 32 31 31 30 33 30 39 4e 30 41 4e 43 2d 42   B02110309N0ANC-B
0070   52 47 30 41 30 35 31 38 33 38 33 44 31 30 31 32   RG0A0518383D1012
0080   44 32 30 31 30 44 33 30 31 30 44 34 30 31 30 44   D2010D3010D4010D
0090   35 30 31 36 44 36 30 31 30 44 37 30 32 30 30 44   5016D6010D70200D
00a0   41 30 41 2a 2a 2a 2a 2a 2a 2a 2a 2a 2a 44 42 30   A0A**********DB0
00b0   41 4b 39 45 51 2f 43 48 52 49 53 44 43 30 41 20   AK9EQ/CHRISDC0A
00c0   20 20 20 20 20 20 20 20 20 44 44 30 41 4e 30 41         DD0AN0A
00d0   4e 43 20 20 20 20 20 44 45 30 35 20 20 20 20 20   NC     DE05
00e0   44 46 30 35 31 38 33 38 33 45 30 30 35 32 31 34   DF0518383E005214
00f0   39 33 45 31 30 35 45 35 34 44 44 45 33 30 32 36   93E105E54DDE3026
0100   30 45 34 30 34 32 32 36 32 43 30 31 45 35 46 32   0E4042262C01E5F2
0110   38 35 34 33 35 35 30 35 37 33 31 35 36 37 39 32   8543550573156792
0120   37 37 46 36 43 32 30 31 43 32 30 45 36 30 43 54   77F6C201C20E60CT
0130   35 50 57 31 56 79 27 7f 6c 20 1c 02 02 00 41 99   5PW1Vy'.l ....A.
0140   ba 62 69 4f b6 46 17 45 0f ec 9a ab 66 e5 c8 b4   .biO.F.E....f...
0150   d8 8a ca c7 2d c6 6d 24 47 ac c6 c2 69 6d 13 67   ....-.m$G...im.g
0160   9d 0d 9e f3 be 96 36 f5 a3 36 71 cd 32 58 ed 07   ......6..6q.2X..
0170   77 aa 60 8f ca 8d 24 78 52 f5 58 06 51 dc 68 4f   w.`...$xR.X.Q.hO
```

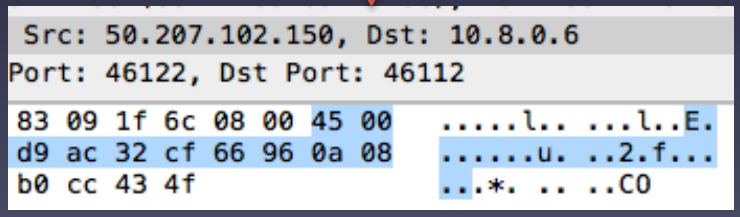
```
...V+.18383.....
.A".%.4Ga.'gM#.A
[...tKA.<j...A.:
2.(...2o.FM.....
F2.*...,RR.m...M
#.q....CP0000030
B02110309N0ANC-B
RG0A0518383D1012
D2010D3010D4010D
5016D6010D70200D
A0A**********DB0
AAB3GD      DC0A
          DD0AN0A
NC      DE05
DF0518383E005214
93E105      E3023
0E4042261C0045F2
8...A.9_.P../%N.
...c..T...mI.b..
`d]CZ.....[..5..
Y..\.L.....Q..;.
.....q
```

WiRES-X Ports

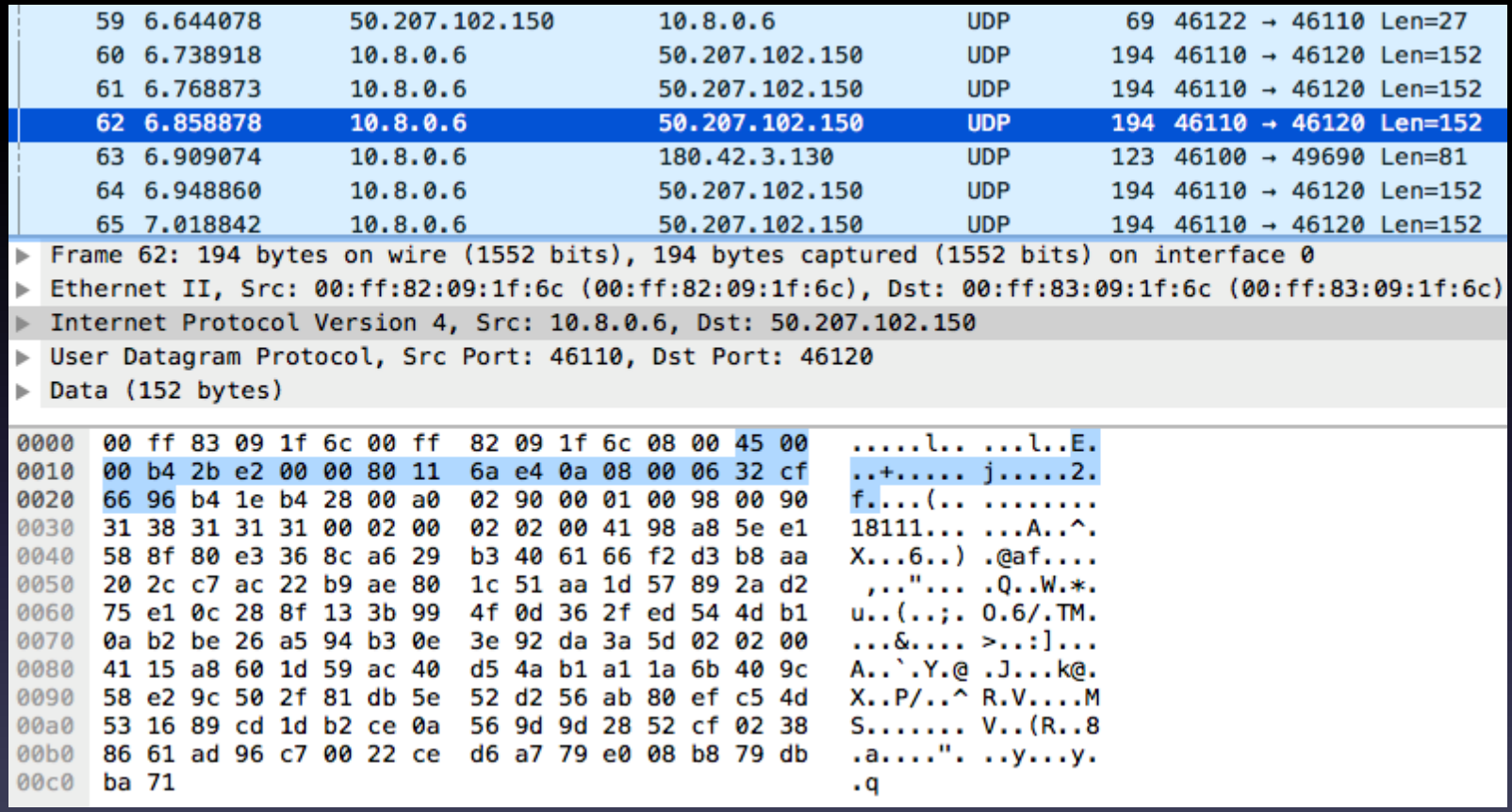
- Ports forwarded to node/room
- Each node is a server
- Every user can create their own Room/reflector
- List Server coordinates connections

Port	Purpose	Destination
46,100	Yaesu List Server	49,690
46,110	Node control	46,110 46,120
46,112	Node voice	
46,114	Room control	
46,120	Room voice	
46,122	News control	46,110 46,122
46,190	Web access	



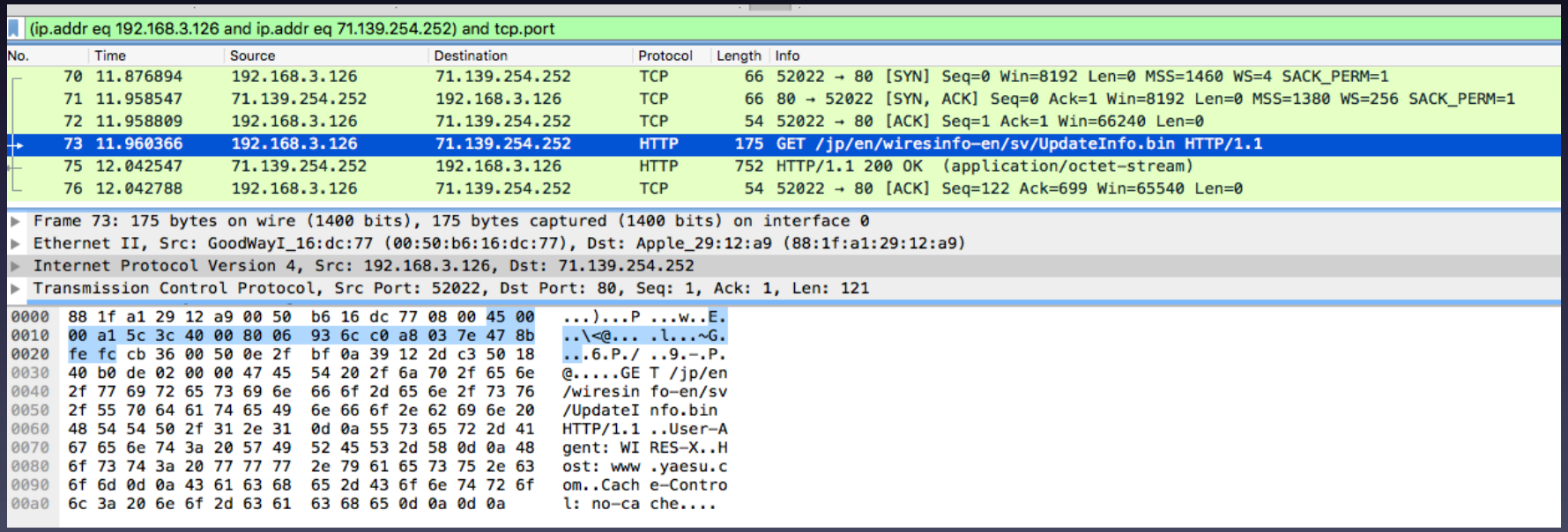


Voice Data Capture



WiRES-X Startup – List Server

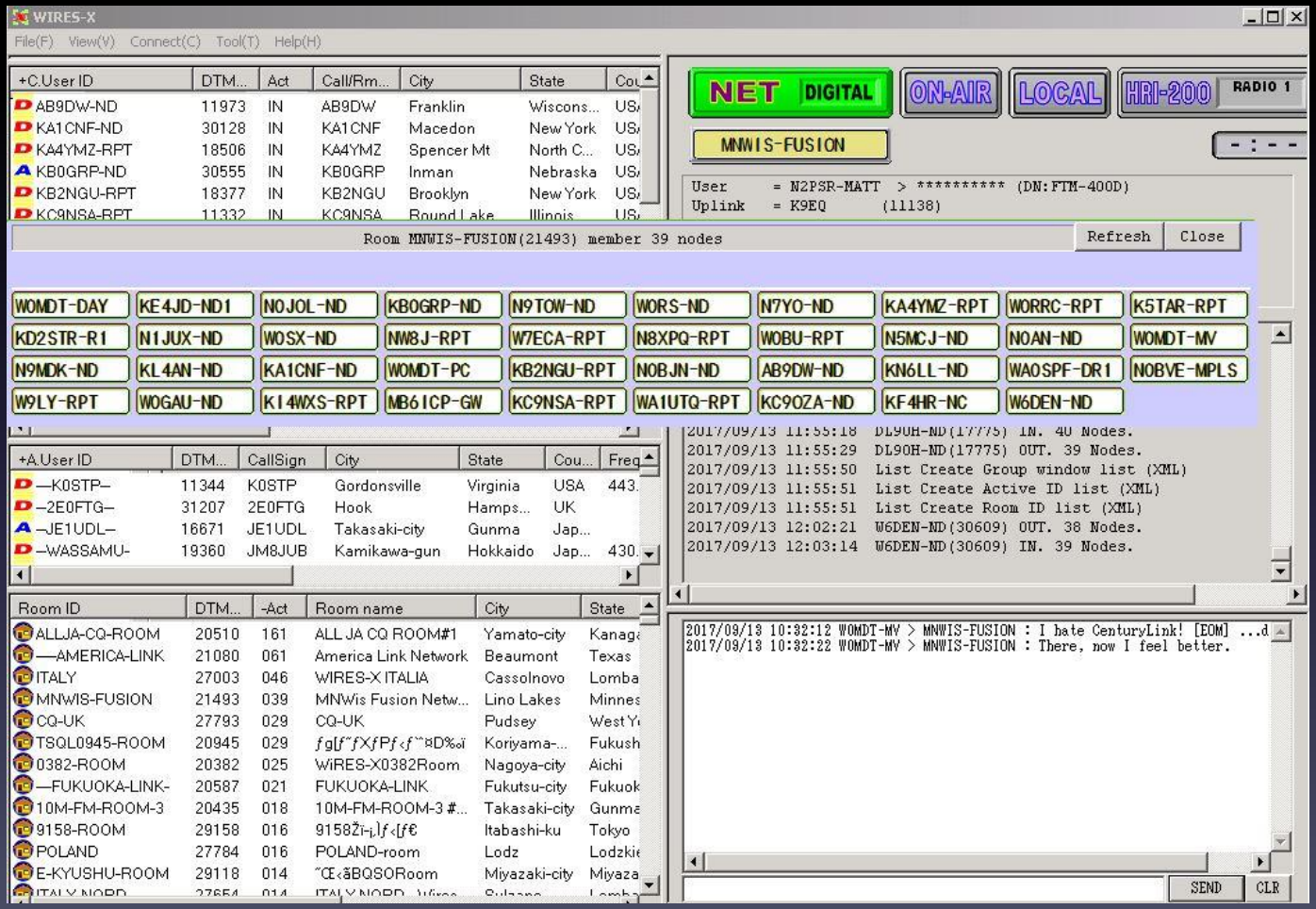
- Load binary configuration file from fixed URL
- Configuration points to multiple List Servers



WiRES-X Data

Data Type	Description
List Server Hello	TCP to fixed URL
List Server initial response	List of resources (servers), configuration
List Server Request	Connection to List Server
List Server Responses	Rooms, Nodes, descriptions, IP address
Status	Update Node, Room and List Server
Heartbeat	Periodic, still alive
Heartbeat response	Reverse heartbeat
Control information	Tx up/down, connect request, disconnect, etc.
Voice	Analog and Fusion OTA data

WiRES-X Console



WiRES-X Software Data

- XML/CSV Data
  - All Nodes*
  - All Rooms*
  - Group ID*
- Logs
  - Node
  - Room
  - News
- Other
  - Access Log (all transmissions)*
  - Diagnostic
- Used by HamOperator.com

WIRES-X Nodes Connected to MNWIS de K9EQ

WiRES-X Room #21493

Updated about every 30 minutes
Number of WiRES-X Nodes Listed: 45
Number of Analog Nodes: 4
Number of Digital Nodes: 35
Number of FCS003-23 Connections: 6

Courtesy HamOperator.com
Report Created: Wed, 13 Sep 2017 18:02:27 Rev. XML=0.8, Python=0.9.3

Do not bookmark this page - it will change. Use HamOperator.com/Fusion/WiRES-X

User ID	ID #	A/D	City	State	Country	Freq	SQL	Comment
KB0GRP-ND	30555	A	Inman	Nebraska	USA			
KF4HR-NC	11019	A	Belhaven	North Carolina	USA			
N0BVE-MPLS	11165	A	Hopkins	Minnesota	USA	145.230MHz-.600MHz	TSQ:114.8Hz	145.230 CHASKA MN PL 114.8
W7ECA-RPT	30406	A	Great Falls	Montana	USA	444.350MHz+5.000MHz	DCS:051	
AB9DW-ND	11973	D	Franklin	Wisconsin	USA	445.550MHz	DSQ:OFF	Dale - Franklin, Wi, USA
JA7UDE-ND	16082	D	Sendai-city	Miyagi	Japan	430.900MHz	DSQ:OFF	
K5KOY-ND	18250	D	Dallas	Texas	USA	445.525MHz	DSQ:OFF	From the Republic of Texas in DFW
KA1CNF-ND	30128	D	Macedon	New York	USA	147.525MHz	DSQ:OFF	West Walworth, NY
KA4YMZ-RPT	18506	D	Spencer Mt	North Carolina	USA			
KB2NGU-RPT	18377	D	Brooklyn	New York	USA			
KC9IL-ND	18113	D	Buffalo Grove	Illinois	USA			
KC9NSA-RPT	11332	D	Round Lake Beach	Illinois	USA			
KE4IDF-TOM	30013	D	Dayton	Tennessee	USA			
KE4JD-ND1	30514	D	Hopkinsville	Kentucky	USA			
KI4WXS-RPT	11170	D	Charlotte	North Carolina	USA			
KL4AN-ND	18462	D	Anchorage	Alaska	USA			
KN6LL-ND	30263	D	Jackson	Wyoming	USA			
N0AN-ND	30158	D	Ogden	Iowa	USA			
N0BJN-ND	30012	D	Little Falls	Minnesota	USA			
N0JOL-ND	30092	D	Isanti	Minnesota	USA			

MNWIS Stations Last Heard de K9EQ

WiRES-X Room #21493, Updated about every 30 minutes

Sorted by date/time when the indicated Transmitter ID was heard.
Stations on W0MDT-MV 444.525 are listed as Local
Courtesy HamOperator.com Rev. Python=0.9.3

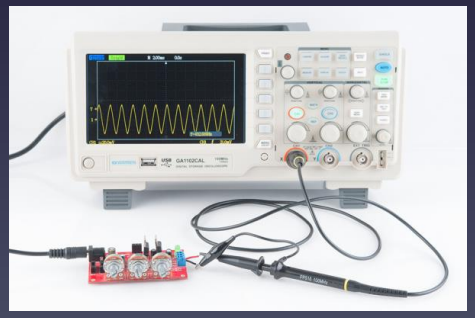
Do not bookmark this page - it will change. Use HamOperator.com/Fusion/WiRES-X

FT1D=12. FT2D=8. FTM-400=40. FTM-100=19. FTM-3200=2. FT70D=3. FT-991=6. Total=90

STATION	CALL	Tx ID	Radio Type	Net or Local	When Heard
W0MTA-MYKL	W0MTA-MYKL	F0Rku	FTM-400	Local	Wed Sep 13 18:00:55 2017
AE0RF	AE0RF	E0bmb	FT1D	Net	Wed Sep 13 18:00:28 2017
K9EQ/R-075	K9EQ/R-075	E0DoV	FT1D	Local	Wed Sep 13 18:00:09 2017
N9GHP/MIKE	N9GHP/MIKE	F0bDK	FTM-400	Net	Wed Sep 13 17:51:25 2017
KC9IL-WRRN	KC9IL-WRRN	F0oWa	FTM-400	Net	Wed Sep 13 17:51:07 2017
N8XPQ-MIKE	N8XPQ-MIKE	F0pvi	FTM-400	Net	Wed Sep 13 17:45:36 2017
N7GYL	N7GYL	E5KL8	FT2D	Net	Wed Sep 13 17:18:32 2017
KC9RHH	KC9RHH	E0i3y	FT1D	Net	Wed Sep 13 16:57:20 2017
KC9OZA	KC9OZA	E0A1S	FT1D	Net	Wed Sep 13 16:55:07 2017
N0JOL-JOE	N0JOL-JOE	F06la	FTM-400	Net	Wed Sep 13 16:52:36 2017
K0ORKCHUCK	K0ORKCHUCK	E51e8	FT2D	Local	Wed Sep 13 16:51:25 2017
K5KOY-KOY	K5KOY-KOY	E5cO4	FT2D	Net	Wed Sep 13 16:47:31 2017
AD0MI-PETE	AD0MI-PETE	F0Ij4	FTM-400	Net	Wed Sep 13 16:44:34 2017
N1JUX/KEVN	N1JUX/KEVN	F54kT	FTM-100	Net	Wed Sep 13 16:34:22 2017
N0JOL-JOE	N0JOL-JOE			Local	Wed Sep 13 16:30:00 2017
W0GAU GREG	W0GAU GREG	F5NGc	FTM-100	Net	Wed Sep 13 16:17:32 2017
KDOJNQ/BSR	KDOJNQ/BSR	G09DZ	FT-991	Net	Wed Sep 13 15:52:27 2017
KA0FOP-JHN	KA0FOP-JHN	E0fSc	FT1D	Net	Wed Sep 13 15:46:18 2017
N2PSR-MATT	N2PSR-MATT	F0IKx	FTM-400	Local	Wed Sep 13 15:22:06 2017

Analysis Tools

- WireShark
  - Wireshark.org
  - FTDIChip.com
- Scanastudio
  - IKALogic.com
- Oscilloscope



TAPR and Manufacturers Discussion

- Could TAPR collaborate with manufacturers on projects?
- What should manufacturers do? What should Hams do?
- Is there opportunity to bring digital benefits to a broad range of non-technical users? (I.e., APRS)
- What Digital Voice needs to do (hint: things analog can't do)
- Potential Projects:
  - Diversity reception for repeaters
  - Multisite digital reception
  - Common receive locations for multiple repeaters

Additional Resources

- Saelig.com – Test Equipment
- SparkFun.com, Adafruit.com, Hacktronics.com, SeeedStudio.com
- Hackaday.com, DIYHacking.com
- Element14.com
- Tapr.org
- Yaesu Digital Standard (Yaesu.com)
- Github software repositories
- Fusion Technical Net Monday 7:30 PM Central (0030/0130 UTC) Room #21493, Internet Streaming: HamOperator.com

73, Chris K9EQ