D-STAR System

Technical Requirements for the Wireless System

1.1 Voice Communication

1.1.1 General Terms

(1) Communication Method
Half-duplex, digitized voice transmissions.

(2) Communication Contents
Digitized voice/audio signals and short data messages are supported. Voice and audio streams are transmitted synchronously to support communications quality reproduction. Data and voice/audio transmissions are interleaved.

1.1.2 Transmitting Equipment

(1) Modulation methods
GMSK
QPSK
4FSK

(2) Data rate
Maximum of 4.8 Kbps

(3) Voice encoding method
AMBE (2020) converting at 2.4 Kbps
FEC at 3.6 Kbps

(4) Occupied bandwidth
Maximum of 6 KHz

1.1.3 Tx / Rx Switching time
Less than 100ms.

1.2 Data Communication

1.2.1 General Terms

(1) Communication Method
Simplex

(2) Communication Contents
Digital data stream is supported.
1.2.2 Transmitting Equipment

(1) Modulation method
   GMSK
   QPSK
   4FSK
(2) Data rate
   Maximum of 128 Kbps
(3) Occupied bandwidth
   Maximum of 150 KHz

1.1.3 Switching time (Tx-Rx)
   Less than 50ms.

1.3 Backbone communication

1.3.1 General Terms
(1) Transmission Method
   Full duplex.
(2) Transmission Contents
   Backbone communication between repeaters containing multiplexed digitized voice/audio, user data, and link control data signals.

1.3.2 Transmitting Setup
(1) Output power
   Complies with FCC regulations.
(2) Modulation method
   GMSK
(3) Data rate
   Maximum of 10Mbps
(5) Occupied bandwidth
   Maximum of 10.5MHz

1.3.3 Multiplexing Method
   The multiplexing method for backbone links is an ATM. The details of the specifications comply with the ATM protocol. Digitized voice/audio signals should be given the highest transmission priority.
   If more data is required, refer to ATM standards.

<table>
<thead>
<tr>
<th>ATM Cell (53byte)</th>
<th>→</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header</td>
<td></td>
</tr>
<tr>
<td>5byte</td>
<td>48byte</td>
</tr>
</tbody>
</table>

2
2. System Interconnection Requirements

2.1 Wireless Communication Packet

The frame structure of the wireless packet is below.

2.1.1 Frame structure of a data packet

<table>
<thead>
<tr>
<th>Radio Header</th>
<th>Data</th>
<th>FCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Syn</td>
<td>Frame Syn.</td>
<td>15bit</td>
</tr>
<tr>
<td>Flag 1</td>
<td>Flag 2</td>
<td>1 byte</td>
</tr>
<tr>
<td>Flag 3</td>
<td></td>
<td>8byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2byte</td>
</tr>
<tr>
<td>ID</td>
<td></td>
<td>4byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46-1500byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4byte</td>
</tr>
</tbody>
</table>

The explanation of the data frame structure the Radio Header follows.

1) **Bit Syn.** (Bit synchronization): Repeated standard 64-bit synchronization pattern (for GMSK 1010, for QPSK 1001). Transmission direction is from left to right.

2) **Frame Syn.** (Frame synchronization) : 15bit pattern (111011001010000). Transmission direction is from left to right.

3) **Flag 1** (8 bit): Flag 1 uses upper 5 bits and lower 3 bits separately.
   A detailed explanation follows.

   | bit 7 (MSB) | Distinguishes between voice and data communications. |
   |            | 1 indicates data, 0 indicates voice. |

   | bit 6      | Identifies if the signal goes through a repeater or is a direct communication between terminals.(1 for repeater, 0 for terminal) |
   |           | Recognizes if communication interruption exists. 1 indicates interruption, 0 indicates no interruption. |

   | bit 5      | Identifies control signal/data signal. 1 represents control signal and 0 represents regular data signal. (Voice signal included) |

   | bit 4      | 1 represents an urgent priority signal, 0 represents a normal priority signal. |
   |           | For signals with a “1” in this position, the receiver will open squelch etc. |

Note, Urgent signal in this document does not mean “Urgency signal” as defined in International Radio Law. It means an urgent priority signal for use in emergency communications.
111=repeater station control flag, while the repeater is controlled, the flag is “111” and the data frame contains control data.  
110=Auto reply 
101=Unused (spare) 
100=Resend flag, requests resending previous frame 
011=ACK flag, Treated as ACK flag 
010=No reply flag, Indicates no reply is available 
001=Relay unavailable flag, Indicates unsuitable relaying conditions. 
000=NULL, No information.

### Upper bit

<table>
<thead>
<tr>
<th>Bit</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data</td>
<td>Relay</td>
<td>Interruption</td>
<td>Control</td>
<td>Urgent</td>
</tr>
<tr>
<td>0</td>
<td>Voice</td>
<td>Direct</td>
<td>No interruption</td>
<td>Control</td>
<td>Urgent</td>
</tr>
</tbody>
</table>

### Lower bit

<table>
<thead>
<tr>
<th>2</th>
<th>1</th>
<th>0</th>
<th>Function</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Repeater Control</td>
<td>Repeater Control Mode</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>(Unused)</td>
<td>(Unused)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>Resend</td>
<td>Requests Resend</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>ACK</td>
<td>ACK flag</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>No Response</td>
<td>Indicates No Response Available</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>Relay Unavailable</td>
<td>Indicates Relay Unavailable</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NULL</td>
<td>NULL</td>
</tr>
</tbody>
</table>

#### (4) Flag 2

Flag 2 is for future expandability and is defined below.

<table>
<thead>
<tr>
<th>Bit</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Default</td>
</tr>
</tbody>
</table>

a. flag is used as an format descriptor. This is available not only for the increase and decrease of a figure of callsign but also for ID, which is not used as callsign rather than numeric. 

b. flag is used only a creator or a manufacturer of the equipment.

#### (5) Flag 3

Flag 3 is used to match control functions to protocol versions, which may be upgraded in future software versions.

<table>
<thead>
<tr>
<th>Bit</th>
<th>Meaning</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000000</td>
<td>No</td>
<td>Default</td>
</tr>
</tbody>
</table>
(6) "Destination repeater Callsign" can have a maximum of 8 ASCII letters and numbers. Blanks should be filled with a space character. In the case of direct communication, it inserts “” and fills the blanks with a space character. The use of this field is described in section 2.2.

(7) "Departure repeater Callsign" can have a maximum of 8 ASCII letters and numbers. Blanks should be filled with a space character. In the case of direct communication, it inserts “” and fills the blanks with a space character. The use of this field is described in section 2.2.

(8) "Companion Callsign" can have a maximum of 8 ASCII letters and numbers. Blanks should be filled with a space character. The use of this field is described in section 2.2.

(9) "Own Callsign 1" can have a maximum of 8 ASCII letters and numbers. Blanks should be filled with a space character. This field same as voice frames.

(10) "Own Callsign 2" is used when to add suffixes to a callsign or an additional destination address information. "Own Callsign 2" can have a maximum of 4 ASCII letters and numbers. Blanks should be filled with a space character.

(11) P_FCS is the Radio Header CRC-CCITT checksum, computed by the following expression.

\[
G(x) = x^{16} + x^{12} + x^5 + 1
\]

(12) The data frame of the packet is constructed as an Ethernet packet.

(13) FCS is the checksum of the Ethernet data payload. It is a CRC-32 checksum as defined in ISO3309 and is computed by the following expression.

\[
G(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^5 + x^2 + x + 1
\]

### 2.1.2 Frame structure of voice packet

<table>
<thead>
<tr>
<th>Bit</th>
<th>Frame</th>
<th>Flag 1</th>
<th>Flag 2</th>
<th>Flag 3</th>
<th>ID</th>
<th>Own Callsign 1</th>
<th>Own Callsign 2</th>
<th>P_FCS</th>
<th>Voice Frame</th>
<th>Data Frame</th>
<th>Voice Frame</th>
<th>Data Frame</th>
<th>Voice Frame</th>
<th>Data Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syn</td>
<td></td>
<td>Syn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syn</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syn</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>660bit</th>
<th>16byte</th>
<th>24byte</th>
<th>24byte</th>
<th>24byte</th>
<th>2byte</th>
<th>72byte</th>
<th>24byte</th>
<th>72byte</th>
<th>24byte</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>___←byte error correction ___</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The explanation of the voice packet including the voice and data frames follows:

(1) The Radio Header has the same frame structure as for the data packet.

(2) Data part includes 72-bit voice signal frames with a length of 20ms in order of their output from the CODEC according to the AMBE (w/FEC) specification. Data frames contain 24-bits of data.

(3) The first data frame and then every 21st data frame in a repeating cycle, are used only for synchronizing data for each modulation type. Synchronization corrects for the lag between transmission and reception, including the transit time of communications. This synchronized signal contains a 10-bit synchronized signals and two 7-bit Maximal-length sequences “1101000” patterns. (24 bits total). Transmission direction is from left to right.

(4) The data in a data frame is transmitted without modification from the input data. If the data is required as error correction or synchronization, these frames are processed before processing the data input.

(5) If the data signal length is greater than the length of the voice communication the transmitting switch is turned on until the completion of the data signal manually. The processing can be allowed automatically.

(6) The last data frame, which requires a means of terminating the transmission, is a unique synchronizing signal (32 bit + 15bit “000100110101111” + “0”, making 48 bits) as defined by the modulation type. Transmission direction is from left to right.

2.2 Communication protocol

Note: In the following descriptions, _ (under-bar) indicates a space character, ASCII $20. If the callsign field has blanks between the callsign's last letter and last character in the field, the blanks should be filled with a space character.

2.2.1 Callsign

The Callsign field of the radio header of data and voice packets is used for packet routing. Except for the callsign in the “Own station” fields, callsigns generally have less than 6 letters (or 7 letters). The following paragraphs show how to interpret callsign fields:

(1) “Destination repeater Callsign”

In zone communication, this field must be set to the callsign of the repeater utilized by the companion station.

If there are multiple repeaters in a repeater site, they are distinguished by last character, of “A”, “B”, “C”, or “D”. (Ex. W$1AAA_A, W$1AAA_D, etc.) The default character is “A”.

(Explained callsign is not to exist as W$1AAA but only for examples)
When communicating outside the local zone, which is called zone to zone communication, this field must be set to the callsign of the zone repeater connected to a gateway and last character set to “G” to indicate communications via the gateway. (Ex. W$1AAA_G)

(2) "Departure repeater Callsign"
This field must be set to the repeater callsign of the originating station.

If there are multiple repeaters in a repeater site, they are distinguished by last character of “A”, “B”, “C”, or “D”. (Ex. W$1AAA_A, W$1AAA_D etc.) The default character is “A”.

(3) "Companion Callsign"
The field must be set the callsign of the companion station with which communication is desired. If the station has multiple radios, they are distinguished by last character of “A”, “B”, “C”, “D”, “E”, or “F”. (Ex. W$1AAA_A, W$1AAA_F etc.)

When originating a non-directed call, the field should contain “CQCQCQ”.

When calling CQ to a non-local zone, which is called zone to zone communication, prepend “/” to the destination repeater callsign. If there are multiple repeaters in a repeater site, they are distinguished by last character of “A”, “B”, “C”, or “D”. (Ex. W$1AAA_A, W$1AAA_D etc.) The default character is “A”.

To access a repeater with a local server, in “Companion Callsign”, the field should contain the repeater callsign and set last character to “S”. (Ex. W$1BBB_S)

(4) "Own Callsign 1"
The “Own Callsign” field contains the own station's callsign. If the station has multiple radios, they are distinguished by last character of “A”, “B”, “C”, “D”, “E”, or “F”. (Ex. W$1AAA_A, W$1AAA_F etc.)

(5) "Own Callsign 2"
This field contains information to display as in after a “/ (slash)”. (Ex. W$1AAA_F / JD1 etc. Note: “/” is not displayed). The purpose of “Own Callsign 2” is to allow “Own Callsign 1” to contain as complete a callsign as possible. “Own Callsign 2” is not evaluated by the system's identification functions.
Appendix

AP1 Scrambler
Scrambling is implemented as follows to eliminate errors when the same bit patterns are received continuously.

AP1.1 Scramble codes

\[ S(x) = x^7 + x^4 + 1 \]

Initialization defines . Initialization begins the scrambling process.

![Scramble codes diagram](image)

AP1.2 Data packet scrambling

Voice packet scrambling includes the radio header and data frames except for synchronizing frames. Synchronized signals and the last frame are not scrambled.

![Data packet scrambling diagram](image)

AP1.3 Voice packet scrambling

AP2 Error Correction
Error correction for data voice packets is performed as follows.
The error correction range is from Flag 1 to P-FCS.
The error correction signal is interleaved with the packet data with a convolutional rate of 1/2, a constraint length of 3, and a depth of interleave of 24.

### The structure of encoder
- Convolution code
- Convolutional code rate / Constraint length
- Handover bit
- Generator polynomial
  - $G_1(D) = 1 + D + D^2$
  - $G_2(D) = 1 + D^2$

### Composing process
1. X1, X2 registers must be set to zero before encoding.
2. Feed header data into the encoder beginning with the LSB.
3. Following the header data, including P_FCS, input two zero bits.

### AP3 Interleave process
To reduce continuous burst errors during the radio header, the interleaving process specified by the following interleave matrix is used. The interleave process operates independently of the error correction process.
- To interleave transmit error correction, input the packet data stream from left top to the bottom. Read the interleaved data stream from left top to right.
- To separate the error correction data and original data stream, input from the received data stream from the left top to right. Read the output data stream from the left top to the bottom.
### Interleave Structure Matrix

#### (ms) 0.2 0.4 0.6 0.8 1 1.2 1.5 1.7 1.9 2.1 2.3 2.5 2.7 2.9 3.1 3.3 3.5 3.7 4 4.2 4.4 4.6 4.8 5 5.2 5.4 5.6 5.8

| Time (ms) | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 | 2.7 | 2.9 | 3.1 | 3.3 | 3.5 | 3.7 | 4 | 4.2 | 4.4 | 4.6 | 4.8 | 5 | 5.2 | 5.4 | 5.6 | 5.8 |
|-----------|---|-----|-----|-----|-----|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|-----|-----|-----|-----|---|-----|-----|-----|-----|
| 0.2       | 0  | 24  | 48  | 72  | 96  | 120| 144 | 168 | 192 | 216 | 240 | 264 | 288 | 312 | 336 | 360 | 384 | 408 | 432 | 456 | 480 | 504 | 528 | 552 | 576 | 600 | 624 |
| 0.4       | 0  | 25  | 49  | 73  | 97  | 121| 145 | 169 | 193 | 217 | 241 | 265 | 289 | 313 | 337 | 361 | 385 | 409 | 433 | 457 | 481 | 505 | 529 | 553 | 577 | 601 | 625 |
| 0.6       | 0  | 26  | 50  | 74  | 98  | 122| 146 | 170 | 194 | 218 | 242 | 266 | 290 | 314 | 338 | 362 | 386 | 410 | 434 | 458 | 482 | 506 | 530 | 554 | 578 | 602 | 626 |
| 0.8       | 0  | 27  | 51  | 75  | 99  | 123| 147 | 171 | 195 | 219 | 243 | 267 | 291 | 315 | 339 | 363 | 387 | 411 | 435 | 459 | 483 | 507 | 531 | 555 | 579 | 603 | 627 |
| 1         | 0  | 28  | 52  | 76  | 100 | 124| 148 | 172 | 196 | 220 | 244 | 268 | 292 | 316 | 340 | 364 | 388 | 412 | 436 | 460 | 484 | 508 | 532 | 556 | 580 | 604 | 628 |
| 1.2       | 0  | 29  | 53  | 77  | 101 | 125| 150 | 174 | 198 | 222 | 246 | 270 | 294 | 318 | 342 | 366 | 390 | 414 | 438 | 462 | 486 | 510 | 534 | 558 | 582 | 606 | 630 |
| 1.5       | 0  | 30  | 54  | 78  | 102 | 126| 151 | 175 | 200 | 224 | 248 | 272 | 296 | 320 | 344 | 368 | 392 | 416 | 440 | 464 | 488 | 512 | 536 | 560 | 584 | 608 | 632 |
| 1.7       | 0  | 31  | 55  | 79  | 103 | 127| 152 | 176 | 201 | 225 | 250 | 274 | 298 | 322 | 346 | 370 | 394 | 418 | 442 | 466 | 490 | 514 | 538 | 562 | 586 | 610 | 634 |
| 1.9       | 0  | 32  | 56  | 80  | 104 | 128| 153 | 177 | 202 | 226 | 251 | 275 | 299 | 323 | 347 | 371 | 395 | 419 | 443 | 467 | 491 | 515 | 539 | 563 | 587 | 611 | 635 |
| 2.1       | 0  | 33  | 57  | 81  | 105 | 129| 154 | 178 | 203 | 228 | 253 | 277 | 301 | 325 | 349 | 373 | 397 | 421 | 445 | 469 | 493 | 517 | 541 | 565 | 589 | 613 | 637 |
| 2.3       | 0  | 34  | 58  | 82  | 106 | 130| 155 | 179 | 204 | 229 | 254 | 278 | 302 | 326 | 350 | 374 | 398 | 422 | 446 | 470 | 494 | 518 | 542 | 566 | 590 | 614 | 638 |
| 2.5       | 0  | 35  | 59  | 83  | 107 | 131| 156 | 180 | 205 | 230 | 255 | 280 | 304 | 328 | 352 | 376 | 400 | 424 | 448 | 472 | 496 | 520 | 544 | 568 | 592 | 616 | 640 |
| 2.7       | 0  | 36  | 60  | 84  | 108 | 132| 157 | 182 | 207 | 232 | 257 | 282 | 306 | 330 | 354 | 378 | 402 | 426 | 450 | 474 | 498 | 522 | 546 | 570 | 594 | 618 | 642 |
| 2.9       | 0  | 37  | 61  | 85  | 109 | 133| 158 | 183 | 208 | 233 | 258 | 283 | 308 | 332 | 356 | 380 | 404 | 428 | 452 | 476 | 500 | 524 | 548 | 572 | 596 | 620 | 644 |
| 3.1       | 0  | 38  | 62  | 86  | 110 | 134| 159 | 184 | 209 | 234 | 259 | 284 | 309 | 333 | 357 | 381 | 405 | 429 | 453 | 477 | 501 | 525 | 549 | 573 | 597 | 621 | 645 |
| 3.3       | 0  | 39  | 63  | 87  | 111 | 135| 160 | 185 | 210 | 235 | 260 | 285 | 310 | 334 | 358 | 382 | 406 | 430 | 454 | 478 | 502 | 526 | 550 | 574 | 598 | 622 | 646 |
| 3.5       | 0  | 40  | 64  | 88  | 112 | 136| 161 | 186 | 211 | 236 | 261 | 286 | 311 | 335 | 359 | 383 | 407 | 431 | 455 | 479 | 503 | 527 | 551 | 575 | 600 | 624 | 648 |

Interleave structure matrix, showing the interleaving pattern for different time intervals in milliseconds (ms). Each row represents a time interval, and the values in the matrix correspond to the interleaved structure at that time. The matrix is structured to show the progression of interleaving over the specified time range.
Lexicon

Gate way (GW)
   Equipment of to connect between a zone repeater and the Internet. Usually it is normal PC including D-STAR GW softwares.

Zone
   A region of connected multi repeaters by backbone repeaters.

Zone repeater
   Connected a repeater to the Internet in a zone.

Repeater area
   A region of available to access a repeater to the terminals.

Repeater site
   A place of setting some repeaters and/or backbone repeaters.