

Digital Modes for the Novice: The Big Three

If you are an amateur radio operator in 2016, then I am sure you have heard of the digital modes: D-Star, DMR or Fusion. You may want to 'go digital' but not sure where to start. Which way to go? The purpose of this page is to compare the relative merits and weigh up the various pros and cons of each.

Not until the end will you learn my first choice. I have a hotspot based on a Raspberry PI and can use all of three modes I will compare. There are additional digital modes like Apco25 (used widely in the USA), Digital PMR446 and Digital CR that I haven't used and are also much less common and that I will not include. Although supported by my AOR AR-DV1 pictured below, I do not currently have enough knowledge or experience of those modes to represent them. Anyway, there is no infrastructure for them in the UK. So, I will focus on the big three: DMR, Yaesu Fusion and D-Star.



The AOR AR-DV1 pictured above on a field trip to Cambridgeshire supports: DMR, D-Star, Fusion, Apco25, NXDN, Digital PMR446, Alinco Digital, and Digital CR, as well as FM, AM, CW, USB and LSB. Coverage is from 100 KHz to 1300 MHz and, rather unusually, and mode is available on any frequency. Location was at 52.155463N, 0.205664E which is a high point in the Gog Magog hills south of Cambridge –a location I used to use for DXing when I lived in Cambridge; it is a vantage point in an otherwise flat area where you can see and RX for miles – in the old days I used to do TV Dxing from there as well as amateur radio.

I want to make sure up front that I am unbiased and impartial: this is not intended to promote any one mode over the others. I do not work for any supplier of equipment, rather I like all forms of radio and really do not agree with a stance that is biased toward one mode, and against others. Each of these modes has a place and my aim is to help you decide which one fits your station and way of operating. I am going to start off with a quick synopsis of each of the big three.

DMR

Digital Mobile Radio is known as DMR and sometimes you will hear it referred to as Mototrbo. Mototrbo is actually the Motorola implementation of the DMR protocol. DMR originated as a business communication standard in Europe. It is important to note that it was created for business communications; this will help to explain some of its limitations such as the lack of 'in the field' programmability. There are many manufactures of radios for DMR, so there is excellent choice of equipment, and a wide price range. So far as voice communications go, equipment from different manufactures are compatible, although some features such as text messaging are not always compatible (some radios allow the proprietary format to be changed to a standard messaging format which should make messaging compatible). The messaging feature can be used to confirm call signs, contact details and the suchlike.

D-Star

Of the 3 modes, D-Star is the oldest. It was devised by the Japan Amateur Radio League (JARL) and is actually an open standard. It is important to note that it was created for Amateur Radio usage and therefore offers plenty of opportunity for experimentation. Most people associate Icom with D-Star as they have long been the primary manufacturer of D-Star equipment; however, they are just a manufacturer that has implemented this open standard into their products. There are other manufactures that make add-on boards for D-star to make their equipment compatible. There are also a lot of other solutions for getting on D-Star that do not require a radio or local repeater. We will discuss this topic later.

Yaesu Fusion

Mostly referred to simply as Fusion, this is the newest digital radio mode of the three. It was designed by Yaeasu and is not an open standard; it is proprietary. Be aware that Yaeasu is therefore the only manufacturer of radios for this mode. Yaeasu repeaters are true multi-mode capable and can replace an existing analogue repeater while still providing digital capabilities. It can also transcode an incoming digital signal to analogue or an incoming analogue to digital or it can simply re-transmit what it receives, no matter if it is digital or analogue. Yaeasu offered a special price to radio clubs and groups. Yaeasu almost gave away repeaters for under £500! Clubs with old repeaters to replace and considering digital modes saw that as a great time to update their repeaters. Because of that some countries have many Fusion repeaters. Although the user base is often still primarily analogue. The following is a comparison chart of features of each mode then after the chart I discuss each feature listed and go into more detail on each mode.

<u>Performance Criteria</u>	<u>D-Star</u>	<u>DMR</u>	<u>Fusion</u>
Overall Ease Of Use	Easy	Easy	Easy
Ease Of Programming	Medium	Low	High
Price Range	Low-Medium	Low-High	Medium
Overall Flexibility	High	Low	High
Network Robustness	High	Low	Low
Network Extendibility	High	Low	Low
Number of Manufactures	Few	Lots	One
Network Access without radio?	Yes	No	No
Multi-band Radios	Yes	No	Yes
Programmable in the field?	Yes	Some	Yes
Network Connect ability	Yes	Yes	Yes
Voice Audio Quality	Good	Great	Great
Digital (Call sign) ID	Yes	No	Yes
GPS Facility	Yes	No	Yes
User Data Coms	Yes	No	Yes

Bandwidth {KHz}	6.25	12.5	12.5 / 6.25
Concurrent Voice Channels	1	2	1
Forward Error Correction (FEC)	Good	Excellent	Excellent
Mixed Mode Repeaters?	No	Very Limited	Yes
Ease of Multi-User Usage	Good	Poor	Good

Now let's go through each key point about each mode.

Overall Ease of Use

All of these modes are easy to use once your radio is programmed. They are more involved to set up than analogue (you cannot just use your radio out of the box!). However, *once programmed* none of them are difficult *to use*. If I had to pick the mode that is easiest *to use*, it would be DMR. As we will discuss in more detail below, DMR is not as flexible and therefore, it is anyhow easier to use for a beginner.

Ease of Programming

This is a mixed bag. D-star is not hard to program, however, there is a new concept that you have to understand first and that is routing. If you have any experience with computer networking then this comes as natural to you. With D-star you can talk to your local repeater, another repeater, a reflector which can have 10 or even hundreds of repeaters connected to it or even just an individual person. This sounds complex for a beginner and takes getting used to, but routing is what makes this mode versatile and flexible. As previously mentioned, this mode was designed with amateur usage in mind.

I put DMR into the low category here because depending on the radio you have determines how complex it is to program. The concepts initially sound simple but they are complex to implement. You have to know what each repeater is carrying as far as talk groups are concerned, and on which timeslot. These radios are programmed in the commercial sector by 'someone who knows what they are doing', not by the end user. Another issue here is that some of the commercial DMR radios (in particular Motorola's) require some very expensive software to program them unless you have a pirated copy and are willing to take the usual virus risk. The customer programming software for Hytera equipment can be freely distributed if you can manage to find it online as I found out myself!

For Fusion, programming is not much more difficult than for an analogue radio, because by itself Yaesu Fusion has no connect ability and it is nothing more than a standalone repeater. If your repeater has the optional add-on (known as Wires-X) enabled – what a name (!) it is a little more complicated but for just the radio side of things, it is almost as straightforward as programming an analogue transceiver.

Price Range

Again, even within each mode this varies hugely. You can pay from about £80 up to telephone numbers for a radio! For D-star, the primary manufacturer has been Icom, there are other manufactures of add on boards for other makes of radio. Check before you buy! The Icom gear I would say is in the medium to high price range. However, for less than £100 you can get a USB based device that you plug into your computer and you are on the D-Star network and can talk with your computer to any repeater, reflector, etc. I have never liked this approach as you are tethered to the computer and it ‘doesn’t feel like real radio’ but it is convenient and cost effective. An entry level handheld for D-star is around £250 or thereabouts.

The cost of DMR radios is variable; there are many manufactures of radios for DMR. You can get a Tytera radio for < £100 or go up to a Motorola radio at > £500. You know your budget!

With Yeasu being the only manufacturer of radios for Fusion, you are limited. The entry level handheld radio for System Fusion is around the £250 price mark.

Overall Flexibility

This is a category where opinions may differ - I consider D-star and System Fusion flexible and DMR inflexible. I will explain my reasons.

On D-star, if I want to listen to a specific reflector or connect to a repeater anywhere in the world I can do that through any local repeater within range of my QTH. Or my own hotspot (of which more later), other USB devices connected to my computer and so forth. If I am using my local repeater, I do not have to have the repeater owner do anything I wish to.

System Fusion works similarly if there is a Wires-X node available at the repeater. There is nothing required of the repeater operator and you can connect to any other Wires-X enabled repeater.

DMR has no such flexibility. The repeater operator decides what talk groups he wants to allow, which ones are user activated and on which timeslot, although they are generally standardised between repeaters. He tells the C-bridge operator what he wants and if the operator agrees that is what you can use. If you have a friend that is on a different talk group, too bad, you cannot use it. For example, we lost the use of talk group three to call North America directly. What is available is fixed and not flexible at all.

You have to remember that DMR was created for commercial use where they do not need the flexibility. They want equipment ready to use and simple for the operator. As well as idiot proof. Unfortunately this does not match the amateur radio ethos.

Network Robustness

When I talk survivability I am referring to network failure or natural disaster putting infrastructure out of action. Each mode works very differently and has different topology.

All modes have repeaters can be used as a conventional repeater, as we do on talk group 9 on DMR repeaters.

D-star uses regular internet DNS to connect its nodes. If one node goes down, it does not affect your ability to connect to another one. Of the 3 Modes, this is the most survivable mode; there is no reliance on a central control system.

DMR networking requires it be connected to a C-bridge serving typically a smaller country, or a region of a larger country. I think some explanation is called for here. Unlike the Fusion and D-Star repeaters, DMR requires a central controller called a C-bridge to function. Think of it like the dumb terminals of old mainframes that displayed the data, took input but sent it all back to the mainframe to process.

The problem is if the C-bridge becomes unavailable the repeater can only work locally, it can't route around the C-bridge to other repeaters that are still working. So as an example, if your repeater is connected to a C-bridge in the United Kingdom - if something happens, freak weather, vandalism, or someone accidentally cuts through the cable to the C-Bridge, all UK DMR repeaters just went offline as a network until that is fixed. Because of this dependency on the centralised control, I rated this as a low.

I rated System Fusion as a low also; I know the central controller for the Wires-X nodes is based in Tokyo! Not re-routable at all. At least DMR has a C-Bridge in the UK which is slightly preferable.

Network Extendibility

So - what do I mean by extendibility? Basically this is with regard to anything beyond a local repeater – anything used to network repeaters over wide areas. For all 3 modes, there is a device called a DV4Mini that allows you to access the network for D-Star, DMR and Fusion. To use this you must have a radio that can operate in the 70cm band for the mode you want to use (it operates as a 10mW repeater in essence). So you must have a D-star, Fusion or DMR radio in addition to the DV4Mini. So why rate DMR and Fusion low?

The DMR currently available on the DV4Mini is tied to the Hytera DMR network and most repeaters are tied in the DMR-Marc (Phoenix) network run by Motorola! Motorola will not permit hotspots on their network for reasons best known to themselves. So, you can talk anywhere on the Hytera network but that is not the most common network in terms of coverage or repeater count. With Fusion, yes you can use it but without Wires-X. Also, in

both modes, you cannot easily change talk groups or rooms from your radio; you have to change it in the software. Urgh.

For D-star flexibility comes as standard! The DV4Mini is one of several options using a Raspberry PI and have your own mini repeater – which requires no NOV to use; there are USB dongles like the Star*DV that plug in via USB and you can connect up a Icom Microphone and use it just like a radio over the internet from anywhere you can get online, even using a smartphone! This is a DV4mini used with a Raspberry PI computer - this approach avoids tying up a PC as a hotspot. The DV4mini can even be used with a Windows Smartphone as well as with a Linux system.



Left: a DV4Mini being used with a Raspberry PI computer. I like this approach as it avoids tying up a PC (important if you have family!), as well as requiring less power and being easy to 'put out of harm's way'. It can be located anywhere within WI-FI range or be connected via wired Ethernet. It supports multiple digital modes and incorporates a low power 70cm transceiver (10mW max power output). Choose a quiet frequency within 70cm in your area – no NOV required.

There are a number of USB dongles like the ThumbDV, DVDongle, and others. If you wanted to create your own repeater (for which an NOV is needed), free software on a Raspberry PI, a low cost GMSK modem and one or two radios that have the din data plug in the back and you are up and working. If you are an experimenter, then of the 3 modes, D-Star is the way to go.

Number of Manufactures

Of all of the modes, DMR has the most manufactures of radios and the most choice by far. Because of the large number of manufacturers you have a wide range of prices as well. The low end Chinese radios start at about £80 but the high end and very reliable ones like the Motorola's go over £500.

Icom is still by far the main manufacturer for D-.Star other manufacturers have cards you can install to make their equipment D-star capable but none are nearly as popular as the Icom radios. As stressed above Yaesu is the only manufacturer for System Fusion.

Ease of Multi-User Usage

I wanted to mention this as it demonstrates how DMR is not flexible. On both D-Star and Fusion, when you connect to another node, anyone that is listening on that repeater hears you on the repeater and can tell you have connected to another.

In DMR you simply get booted off of user activated talk groups in particular, in mid-QSO or even in mid-sentence – this really annoys me! On DMR the repeater operator specifies which talk groups are available, on which timeslot and which ones are user activated, for

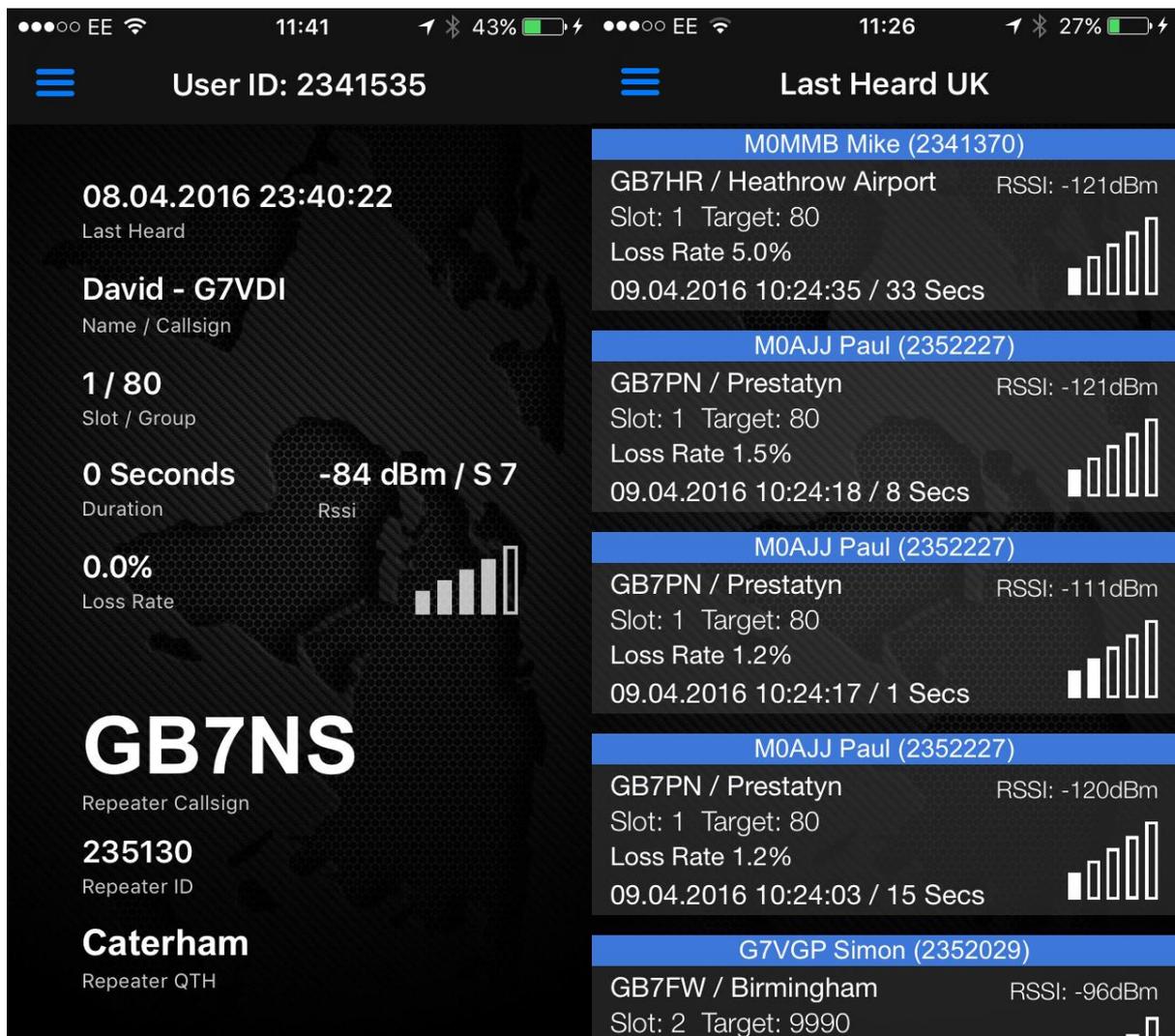
example groups 80 and 81 in the UK are user activated. On your DMR radio you select what talk group you want to use. However, say you want to use a user activated group, you have to tell the repeater by keying up on that talk group. If you get a 'channel busy' error when you try to key up, it is due to another talk group being already in use which uses the same timeslot. DMR radios do not tell you which talk groups or timeslots are already in use in receive mode.

If someone is using a user activated group and someone appears on a non-user activated group, the C-Bridge then suddenly drops the link for the user activated group to the repeater.

So you are in QSO and suddenly you or the person you are listening to just get booted off. And what is more, you cannot regain access until the talk group which got you kicked off the repeater goes quiet! The person who got you kicked off also has no idea that they caused it to happen. This happens often in busy areas of the country.

You can of course set up a receive group list (on a channel you don't transmit on) to monitor all possible talk groups available on each repeater you use to avoid causing this problem yourself, but it does not prevent others from getting you kicked off repeaters. Infuriating!

This free app for Samsung and iPhone gives you a breakdown of the DMR activity on the UK C-Bridge. It even tells you what signal strength your local repeater is receiving you at. It does make up for some of the system information which D-Star radios in particular provide but DMR radios do not display to the end user. The information is updated almost in real time. At least this can tell you at UK wide and single repeater level which timeslots and talk groups are active. Otherwise the only way of knowing there is activity is via the channel busy indicator on your DMR radio.



Accessing the Network without a Radio

Sometimes it is useful to be able to access the network via a computer or smartphone. This goes hand in hand with the extendibility section above. At current D-Star is the only mode that has the ability to connect to it without a radio involved at all. Worth bearing in mind for those times you haven't got a radio with you.

Multi-Band Radios Available?

Both D-star and System Fusion have radios that work on both 2 metres and 70cm. However, DMR does not. So if you live in an area where you have both 2 metre and 70cm DMR repeaters, you need two transceivers. Why would this be? If the radio is intended for business use, your licence is for one band or even frequency. So why pay for a radio which is dual band? At time of writing, the UK has only two 2 metre repeaters in operation, so for 90%+, 70 cm is the way to go. Most other countries primarily have their digital networks predominantly on 70cm as a rule; the wider bandwidth of the 70cm band is part of the reason.

‘In the Field’ Programmable?

The D-Star and Fusion radios are all field programmable. For DMR it is a bit of a let-down. Some of the new DMR radios allow you to program them from the keyboard, however even those few that do come by default not allowing you to program them in the field; you have to use the expensive or sometimes hard to obtain PC programming software to turn on that feature.

Most DMR radios do not have the option to field program them *at all*. It goes back to it being designed for commercial, business use. The end user gets their radio set up by an engineer; the end user needs not have access to the system setup.

Network Connectability

All of the modes have the ability to connect to anywhere in the world if they are internet connected. Each mode does it differently but there is a big difference between D-Star and Fusion when compared to DMR. In D-Star and Fusion, you tell the repeater or other device you are connected to what node you wish to connect to and it connects. Both of these modes can connect to all nodes on the network. You find a new repeater is available, its number, and you can connect.

In DMR, you cannot do a link request, and you can only use talk groups which are made available on your repeater. To get a new talk group added you have to talk with the repeater operator and if he is willing, get him to ask the C-Bridge manager to add a new talk group.

Voice Audio Quality

DMR and Fusion have excellent voice quality down to about -120dBV (a horrible ropery but copy able FM signal level). It is noticeable especially when you go from analogue FM to either of these modes. D-Star has good audio, much better than analogue at low signal strength, but sounds a bit robotic.

Digital (Call sign) ID

D-Star and Fusion both send your call sign in digital format every time you key up the Mic. Whereas DMR sends a user ID number which you get when you register on the network, not your Call sign. To display the call sign of a station calling, you must program this in manually using the ID number via the customer programming software.

User Data Communication

All of the modes have some form of data facility available, but its usefulness varies greatly. In D-star you can send up to 9600 Kbs data. It is just raw data not formatted messages as with DMR. In DMR you can send text messages, although each manufacturer has their own format (this can sometimes be changed to a standard format, allowing for instance messages to be sent between Motorola and Hytera radios. In Fusion you can send more complex messages.

It would seem more thought was put into System Fusion as far as using the data features without the use of a computer goes. Even a QSL card could be sent.

On D-Star and Fusion, when you hear a contact, there is a header that your radio receives that has details about the user that is connecting. From that point onward, you can see the name of the person, their call sign, and a short message and if they have GPS enabled, you can even see their direction and distance from your location. Great feature.

With DMR, their subscriber ID number is what you get, to see who is calling you would have to enter into your contacts list everyone you know as mentioned above, otherwise there is no user information available except from the C-Bridge. For this reason I recommend the splendid 'DMR Tool' app; there is also the live UK monitor at <http://www.opendmr.net/index.php/live-monitor/>. I have also embedded this on my radio page at <http://cotexfood-trading.com/radio/> - I may later add a similar monitor for other modes at a later date.

GPS Facility

There are radios available for D-Star and Fusion that can provide GPS data. In both D-Star and System Fusion, the GPS data is used to display the direction and distance between 2 contacts. In addition, in D-star you can click on the link in the dashboard and view it on a map. DMR equipment does not support this as far as I am aware.

Spectral Efficiency

Each mode takes a different approach to spectrum usage, but all are spectrum efficient. D-Star uses 6.25 KHz of bandwidth that is 9600 Kbs separated into 2 data channels, one for low speed data and one for the voice data.

DMR uses 12.5 KHz that is time division multiplexed, one for time slot one and one time slot two (I believe that changeover between timeslots happens every 30 mS). This approach allows say a worldwide QSO on slot one and a local one on slot two, simultaneously on the same repeater. This is why DMR is now widely used by business users; it means that two voice channels can be fitted into just one 12.5 KHz channel. As an example, in my workplace, slot one is used by security and facilities use slot two.

Fusion uses either 6.25 or 12.5 KHz. In regular voice mode, 6.25 KHz is used. If you are sending data and talking or are using the mode called voice wide which gives the best audio quality, then occupancy is 12.5 KHz, just like standard FM.

Concurrent Voice Channels

DMR is the only mode that can support more than one voice channel at a time as described in the last section. It can support 2 different voice channels in the same 12.5 KHz bandwidth. DMR refers to these as Timeslot 1 and Timeslot 2, and all radios fortunately know which timeslot is which.

Forward Error Correction

All of these modes have some form of Forward Error Correction (FEC). It is by this means that digital modes give excellent signal to noise ratio up to their threshold of reception (in fact the term signal to noise ratio doesn't really apply to digital modes due to the use of error correction). From my experience DMR recovers from bit errors resulting from multipath reception or fading quickest with Fusion in second place. D-Star is in third place; if you are mobile on the fringe of coverage and get significant packet loss D-Star like the other modes gives unintelligible garbled audio. D-Star takes longer to recover from such errors than the other two modes.

Mixed Mode Repeaters

D-Star does not support mixed mode at all. It has no analogue capability. DMR and System Fusion both do have some analogue capability.

DMR can run in mixed mode but without any networking capability thus defeating the object of using it on amateur bands.

Yaesu Fusion was designed to fully support mixed mode. This allows repeater groups to replace aging analogue only repeaters with ones supporting analogue and Fusion in the hopes that people would adopt Fusion whilst still being able to use their existing analogue equipment. Fusion even supports transcoding from analogue to Fusion and vice versa. Cool.

So, where you go from here? Which mode is the ‘best’ choice for you?

I just went down a long list of good and bad things about each mode. If you got this far, congratulations and thank you for reading.

As you will know if you have kept with me this far, there is not one mode that stands out above the other two; all three modes have their own particular strengths and weaknesses, and you have to decide what is right for you. It is a pity that no transceivers are available supporting all three; you will need three transceivers if you want to use all three modes. For monitoring the AOR AR-DV1 supports all three modes and more besides; it also caters for your regular analogue modes. If you read my review of the AOR AR-DV1 also available on this site you will know what a powerful and versatile communications receiver this is. But no *multimode transceivers* are available thus far. This may change in the future – we have multiband and multimode analogue HF transceivers after all.

I assume if you read this far you are either a newcomer to digital modes investigating which mode to go for or maybe a member of a repeater group.

Of course you would want to pick a mode that you can use in your area. You may live in an area that has all of the modes available, one, two, or you may live in an area that has none.

If you live in an area that has none, then your only option for DMR or Fusion is to look at the DV4Mini. For D-Star the DV4Mini is still an option but if you do not want to spend the money on a radio and the DV4Mini, there are the USB dongles.

If you live in an area with all of the modes, you have a big choice to make. If you like flexibility, extendibility or to experiment avoid from DMR and for experimenter, go for D-Star.

If you want to be able to just turn it on and not have anything confusing after it is set up in the first instance, look at DMR. If you do decide to go for DMR, the question is: do you go for 2 metres or 70cm? The biggest reason I have seen for people going for 2 metres is because you are in one of the few parts of the UK to have a DMR repeater on 2 meters.

From a group perspective you have to first think about its purpose. To talk to people around the world or are you wanting it for Raynet type use? If you are looking more towards an emergency communication system then I would look at DMR. It is much more controllable. You can setup talk groups for the different groups. Also, really think out your talk group layout. In general, the standard is to have national and international groups on slot one and the local and regional groups on slot two.

Is it going to replace an existing repeater? If so, how busy is it already? If you have regular users, how are they going to feel if you take it upon yourself to replace your analogue repeater with a repeater that is 100% digital? Fusion will accommodate both a digital mode and your existing analogue user base. On the flip side, adoption of digital is slower if you give them the option of using both analogue and digital on the same repeater as is best supported by Fusion.

Does the repeater site have internet connectivity available on site? If not, go for Fusion since it does not require direct internet connectivity - Wires-X box does not have to be directly connected to the repeater.

But for D-Star and DMR, you have to have a continuous, working internet connection at the repeater. Assuming you do have internet connectivity, D-Star is the most resilient mode and the most versatile. Fusion is in second place 2nd with DMR coming in last as it is least flexible and resilient.

And - my own first digital mode?

When it comes to technology, most predictions turn out to be uncertain or just plain wrong. Rather like the VHS vs Beta-Max battle of the early 1980s, there may be a clear winner, although I have a feeling that this battle of the modes may well result in a draw since all three modes have their own strengths and weaknesses, and all operators have different patterns of use as well as different requirements.

D-Star has its price counting against it, whereas DMR's Achilles heel is the lack of flexibility (from an amateur perspective) and resilience. The main disadvantage of Fusion is that it is not an open standard - and that ultimately limits your choice of equipment and possibly price.

On the plus side, D-Star lends itself best to experimentation and the spirit of amateur radio, and besides it is flexible and resilient. Fusion is genuinely mixed mode, and allows the user to continue to use existing analogue equipment.

However, DMR has the advantage in that the network in the UK is the most mature (although coverage varies widely throughout the UK at time of writing, and my AOR AR-DV1 tells me it has the most usage in my area!). At the end of the day, my budget is limited, and I have to justify any expenditure alongside how much usage I would get out of it. Ultimately, the more people I can communicate with, the better value I feel I get for my money!

This is the primary reason why I adopted DMR first, with the other modes following later as my time and budget allow.