The Cat and the Squirrel: Fundamentals of Communication

Klaus von der Heide, DJ5HG

This presentation gives an overview on basic principles of digital communication. Three cases are analysed: (1) the confident physical detection of a radio signal with known structure; (2) the unidirectional transfer of information via the radio path; and (3) the dialog via the radio path. Especially, the minimal bidirectional contact and the problem of internet use to communicate QSO-relevant information are investigated.

1. The physical detection of a signal

Let a signal be transmitted via the radio path. The path may distort the signal to some extent, and it adds noise. A receiving operator knows that the signal is sent, and he tries to answer the question: Do I really detect the signal? This is the standard question of a RADAR. We assume that all features of the transmitted signal are known at the receiver, including modulation and the exact timing.

To get an answer, the basic procedure in physics is to compute a distance value d that is a measure of the overall difference between the received signal and the known signal. Then a statistical computation evaluates the probability p by which the determined distance is less or equal to d, if only the noise would be present. Then $c = 1 - p$ is the probability by which the distance value is not the result of noise, i.e. the signal should be present. c is called the confidence in the presence of the signal. If for example $c = 0.95$, this means that in the actual case $p = 0.05$ is the probability that the result comes from pure noise. Since this corresponds to one out of 20 , it only is an indication for a real signal, but the presence of the signal is not really confident. If we can accept one wrong decision out of 100 for presence or not, then c must not be less than 0.99 .

The transmitting station does not intentionally switch between different signals to communicate information which is unknown to the receiver. Therefore, the distance value (or it's inverse the correlation value) does not contain any information transferred via the radio path.

2. Unidirectional digital information transfer

2.1. The basic principle

To communicate information, different messages are represented by different signals on the radio path. The receiver, at least in principle, knows all possible signals. Taking the received signal, the receiver has to make a *decision*, which of all possible messages most likely has been sent at the other end. In the simplest possible case two different signals are used, for example a signal as in the last chapter and the unkeyed signal which is zero everywhere. The receiver does know that these two signals are used to represent the information. What he does not know is, which of both actually is sent. The most important stage at any digital receiver is that where the decisions are to be made, which of the possible signals is most probably sent. The optimal method is to determine the confidence values for all possible signals as described in the last chapter and then to choose the message with the signal that got the largest confidence value.

2.2. Using an alphabet

In order to simplify the representation of large amounts of data, the information in most cases is represented as a sequence of symbols just as a text of latin characters. Often only two symbols are used (binary case). But sometimes other symbols are appropriate. JT44 for example uses pulses of 43 different frequencies.

It depends on the decoder for a possible forward error correcting code where the decisions are made within a receiver :

(a) No error correcting code: There is one decision for each symbol.

(b) Hard-decision decoder: There is one decision for each symbol. The decoder takes the digital decisions as input and corrects symbol errors to a specified amount.

(c) Soft-decision decoder: The decoder takes the real or complex noisy values received for the symbols and decides on the best fitting message out of all possible messages.

All these cases finally result in a "received message". If appropriate codes are used, the rate of erroneous messages (at the same transmitted energy) decreases from (a) over (b) to (c).

2.3. The amount of transferred information

The amount of information that is communicated by a message is measured in bits. It's value is the base-two logarithm of the number of messages taken into account at the receiving end. If the message is represented by a word of n equally likely binary digits then the amount of information is n bits. But we can evaluate the amount of information for other cases too. A good example is the amount of information of an amateur callsign without guest land prefix and without /P or simimilar postfix. Amateur callsigns of six symbols or less satify the following scheme:

position	symbol	number of symbols
1	digit or letter or blank	37
2	digit or letter	36
3	digit	10
4	letter	26
5	letter oder blank	27
6	letter oder blank	27

The total number of possible callsigns following this rule is the product of all numbers of symbols in the right column: `#calls = 37*36*10*26*27*27 = 252467280`. The base-2-logarithm of this number is the amount of information that must be communicated in order to identify one out of all callsigns that are generated by this rule:

$$\log_2(252467280) = 27.9115 \text{ bits} \approx 28 \text{ bits}$$

2.4. The difficulty of the decision upon a received message

The difficulty to make the decision upon a message at the receiving end directly depends on the amount of information, i.e. on the number of possible messages. The deciding stage is similar to an analog-to-digital converter.

The gain of error correcting codes, i.e. the reduction of transmission energy to get the same error rate, strongly depends on the amount of information in a message. In a minimal QSO, the theoretical maximum code gain for the confident transfer of a callsign is 6 db. The reachable gain in practise may be about 4 db. There is practically no gain for the transfer of a trivial report and the acknowledgements. That is the reason for the uncoded two-tone shorthand messages of JT65.

2.5 Receiving the own callsign

Usually, there is a QSO-rule that demands for the reception of both callsigns at both ends of the radio path. But the own callsign is known to the receiving station. The difference to the case of a simple physical signalling as discussed in chapter 1 is that the receiving station does not know whether the own callsign is sent or some other callsign. The amount of received information depends on the deciding stage. If it decodes the full callsign, i.e. one out of all possible callsigns as analysed above, then the full information of a callsign also is communicated for the reception of the own callsign. Advantages in this case are that the receiving operator gets the full information who else is worked by the other station, and he also can detect if the other station did not get the own call fully correct. If the deciding stage only gives a confident answer to whether it is the own callsign or not, then the amount of information is not larger than one bit. The increase of knowledge at the receiving end in this case only is that the other station got the own callsign ok or not. It is very much easier to communicate this meta-knowledge via the radio path than to really receive the full callsign.

Information is communicated by different signals. The receiving station, in principle, knows these signals. The information is received by making a decision, which of the signals most probably is sent. The amount of information is not larger than the base-two logarithm of the number of possible choices.

4. The dialog

When I was on the roof of my shack house repairing my small EME-array I observed the following:

A squirrel searched for nuts on the ground three meters away from any tree. The cat saw it and sneaked nearer and nearer. But just at a critical distance, the squirrel saw the cat. It only raised up and looked at the cat. The cat immediately raised up too and started to lick it's leg. The squirrel, seeing this, resumed searching for nuts.

No doubt, that was a dialog, and even more: It was the same as a minimal EME-contact. I try to translate into our words:

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C tries to hide                                       ( inverse CQ de C )
S says: Now I know that you want to catch me          ( C de S )
C says: Now I know that you know that I am here       ( S de C )
S says: Now I know that you know that I will escape   ( RRR )
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Except from the mutual recognition of both animals, all information going hence and forth here is of the type *"I know that you know"* . This knowledge is called *meta-knowledge.* The transfer of an *acknowledge*ment to increase the meta-knowledge at the other end, is fundamental in any dialog. Without the acknowledge, a dialog degrades to a monolog. This dialog between a hunter and it's quarry is very old in the history of nature. Any mistake will cause the death of the quarry or the unsuccess of the hunter.

It is exactly the meta-knowlege which is required at both ends of a radio path to get a valid QSO after both stations have mutually identified each other.

Recently socalled loggers were invented to transfer all the meta-knowledge of a radio contact via the internet while the contact is running. The operators only perform the physical measurement of a known signal. In that case, there is really no decision between different possible signals. So an amount of zero bits of information is communicated via the radio path.

The standard for a QSO to be officially acknowledged usually is as follows:

(1) Both callsigns have to be transferred over the radio path in both directions without error.

(2) A report – of which kind whatsoever – has to be transferred in both directions.

(3) Both stations must get a confirmation from the other end that (1) and (2) have been successful.

My personal reading of this rule is that it claims for **two types of basic requirements**:

(a) **The transfer of a considerable non-trivial message** in either direction for mutual identification (requirement 1)

(b) The successful realization of **a dialog exclusively via the radio path** with at least four very simple transmissions in sequence (requirements 1...3)

Depending on the radio channel in use and depending on the conditions, (a) or (b) may be the crucial part. On VHF and above bands, and propagation modes such as meteor scatter it often is (b) while at very low signal levels (EME, LF, 160m) it is (a). (a) and (b) in combination guarantee that the radio contact at least in principle could be used to exchange further non-trivial information.

It is obvious that there is no common sense on what constitutes a valid QSO. Some of us believe that the simple physical detection of signals that represent the callsigns, the report, and the acknowledgements should be sufficient. Others, as myself, demand for the transfer of the complete amount of information, and for a dialog with a causal sequence of messages. The causality must purely be based on information received via the radio path.

Let AAAAA and BBBBB be the callsigns of two stations. A typical minimal EME-contact has the following principal schedule:

state	message	state	message
(A1)	CQ AAAAA		
		(B1)	AAAAA BBBBB
(A2)	BBBBB AAAAA OOO OOO OOO		
		(B2)	AAAAA BBBBB RO RO RO
(A3)	BBBBB AAAAA RRR RRR RRR		
		(B3)	AAAAA BBBBB 73 73 73

One of the requirements is to get the callsigns at both ends correct (a). Here, we will concentrate on the second requirement (b), i.e. on the dialog between the stations until they are confident that the other end got the required qso-information.

The basic problem at both ends is to get the knowledge at what state the other end is, i.e. the knowledge what until now has been received there. If in the example above AAAAA is in state (A2) repeating the transmission BBBBB AAAAAR OOO OOO OOO every odd minute, then in the receiving periods (even minutes) he waits for the RO RO RO, but the result of each reception also may be the message of (B1) because BBBBB possibly did not get anything of the reply from (A2). Within the dialog, the operators must decide from each reception whether the other station still is in the previous state or in the next state (or none of the choices is confident). These binary decisions are the fundamental tasks of a dialog. Any mistake can terminate the contact because in marginal weak-signal and meteor scatter QSOs there is no real chance to correct a mistake via the radio path. The skill of operators is measured at their rate of making mistakes.

If the possibility of making mistakes is eliminated by the use of the internet then the real skill of keeping up a radio contact no longer is a merit.

The problem is not that someone uses the internet to get advice or to test how many db are missing to get a real QSO. The problem is: The operators claim for new squares, new cc etc. But do such contacts really comply with the QSO-rule? What is the basic aspect of an amateur radio contact: Is it the physical detection of a signal, or is it a real dialog via the radio path? Where is the difference between the challenge to detect the signals of a voyager space probe and the challenge to get a dialog via EME complete? In a 2-way QSO it is just the necessity of at least four reliable decisions that makes the dialog difficult. Indeed, the reason to use the logger is just to avoid this difficulty. What must be received is the result of those decisions. The stage at the receiving end where the decisions are to be made is the most important one in a data transmission system. The radio signal only is the carrier of the information. Unfortunately, it is just the decision stage that is replaced by the internet if a logger is used.

In a marginal contact the transfer of meta-knowledge steps the QSO forward. But nearly all received messages may not be confident, then it is the lack of meta-knowledge that dominates the contact. This is well demonstrated the following meteor scatter example:

The author recorded a CQ from a Z3-station and replied. But for many minutes there was no answer. So the transmitter was switched off, and after further five minutes the author left the shack house to cut the grass in the garden. Coming back after 15 minutes he saw a complete reply, meanwhile 12 minutes old. So the transmitter was switched on again and the final RRR sent. Luckily, after three minutes the screen showed a wonderful 73 from Z3. The mistake of impaciency was compensated by the patiency of the other operator. The author will never forget this impressive lesson. With the meta-knowledge going via the internet there will be no increase in operating skill.

Patiency as the ability to endure the lack of any knowledge, what's going on at the other end, is quite different from the patiency of two operators who wait for a signal to come up out of the noise while they are intensively communicating via the internet.

A dialog is more than a bidirectional communication. It is necessary here to reply in a senseful manner. Each reply must contain information on what successfully has been received.

A QSO is a bidirectional contact in which at least the following information must mutually be communicated via the radio path in a causal sequence:
(1) the callsigns for identification, (2) the identified callsigns for verification, (3) a report, and (4) an acknowledgement that the identification at the other end is accepted and that the report has been received —

Or is it the simple physical signalling and not the communication that should make up a QSO?