Commission for
Communications Regulation

Technical Paper

Use of Adaptive Coding and Modulation in terrestrial fixed link bands

Including licensing regime

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1 Foreword

In its current Spectrum Management Strategy Statement[1], the Commission for Communications Regulation ('ComReg') states its intention to encourage operators to use the latest technology and higher order modulation schemes in order to ensure efficient use of radio frequency spectrum. Efficient use of spectrum is of primary concern to ComReg as spectrum is a finite resource, and therefore it needs to be used efficiently in order to ensure that there is fair and equitable access for all users.

With this in mind, ComReg proposes to allow equipment which utilises Adaptive Modulation to be deployed in all terrestrial microwave fixed link bands. The use of Adaptive Coding and Modulation (ACM) provides many benefits to stakeholders in spectrum, as it provides a means of increasing data throughput and capacity over a microwave radio link, without increasing power or the occupied bandwidth, thus making greater use of the spectrum. There are also cost and environmental benefits, as the increase in data capacity avoids the need to deploy additional radio transmitters and receivers, thus minimising power consumption. This Technical Paper sets out how ComReg plans to update the licensing regime for terrestrial fixed link bands to allow for use of ACM.

Alex Chisholm
Commissioner

[1] ComReg Document 08/50: Spectrum Management Strategy Statement 2008-2010

2 Adaptive Coding and Modulation in terrestrial fixed link bands

This section describes the current method for assigning terrestrial microwave link radio spectrum, and then discusses how ComReg will allow for the introduction of Adaptive Coding and Modulation ('ACM').

2.1 Current procedures for assigning frequencies to terrestrial fixed links

ComReg's current Guidelines[2] and Regulations[3] govern spectrum assignment and licensing of fixed point to point links in Ireland. When making an application for a licence to operate a point to point link, certain information must be provided by the applicant, including radio equipment specifications and modulation schemes, antenna details and radiation propagation envelope, link capacity and proposed transmit power.

Included in the equipment specification is the receiver threshold level. This threshold level, required to achieve a 10^{-6} Bit Error Ratio (BER) in the case of digital modulation systems, shown in Figure 1, is the minimum signal strength which must be received at the receiver RF input, in order for the receiver to be able to correctly decode the information being transmitted with a tolerable amount of errors. Should the signal strength at the receiver be less than the level necessary to achieve the 10^{-6} BER, the BER would increase to an unacceptable level (i.e. greater than 10^{-6}), thereby compromising the reliability of the radio link.

The value of the receiver threshold level is dependent on the modulation scheme being deployed for the given radio link. The lower the order of modulation deployed on a given link, the lower the required receive threshold level. A lower receive threshold level facilitates a larger fade margin and allows for a link to operate with more certainty; however the link capacity will be restricted due to the low order of modulation deployed. Conversely, as higher order modulation schemes are deployed, the required receive threshold level increases, meaning that a higher Equivalent Isotropic Radiated Power (EIRP) from the transmitting antenna is required to achieve the necessary levels at the receiver, leaving link more susceptible to outages due to fading.

Currently, all microwave fixed links licensed by ComReg employ a fixed modulation scheme.

[2] Revised Guidelines to Applicants for Radio links – Point-to-Point – ComReg Document 98/14R6

[3] The Wireless Telegraphy (Radio Link licence) Regulations, 1992 (S.I. no. 319 of 1992)

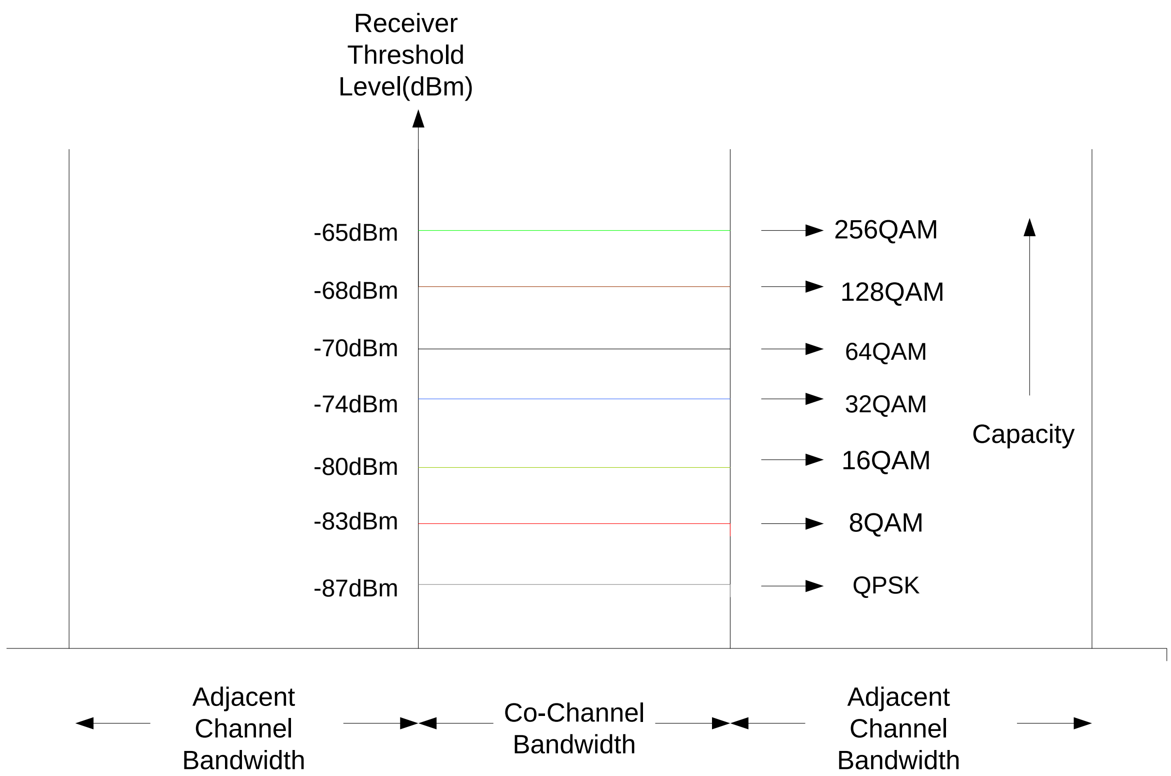

Figure 1: Receiver threshold level varying with modulation scheme

A Radio Frequency (RF) carrier suffers various losses during propagation due to free space attenuation, atmospheric conditions, rain, multipath fading and frequency selective fading. The RF carrier level received at the receive radio unit is inherently proportional to the EIRP from the originating antenna. EIRP is calculated as follows; EIRP (dBm or dBW) = radio transmit power (dBm) + antenna gain (dBi) - associated losses. There are empirical and theoretical radio propagation models which can, to a high degree of accuracy, predict the received RF carrier. Free space path loss is a constant, however the effects of fading can vary dependant on different conditions, for example how heavy it is raining.

The current frequency assignment procedure used by ComReg includes using ITU-R recommended propagation models and data for rain fall (e.g., 32mm/hr for zone 7H which includes Ireland) to calculate typical path losses. Frequencies are assigned to point-to-point radio links in a manner which allows those links, if properly engineered, to achieve certain availability, as outlined in the fixed link guidelines. The availability level which may be achieved by each link is dependent on conditions defined in these guidelines. For example, where a radio site is shared with other fixed links in the same frequency band an operator could achieve a 99.995% availability on a well engineered point-to-point link. This means that, based on the frequencies being used, local terrain conditions, sensitivity of radio equipment, discrimination of antennas and link length, a suitable EIRP would be assigned which would ensure that, theoretically, the link would be operational for 99.995% of each given year, resulting in theoretical outage not exceeding 26.3 minutes per year.

The maximum EIRP permitted on any fixed link is limited on the grounds of spectrum efficiency, as this will ensure that frequencies can be reused throughout the country.

Figure 2 shows the theoretical signal strength at the receiver end of a fixed link in unfaded conditions. It can be seen that this signal is at a higher level than the 10^{-6} BER static threshold. The difference between these two values is known as the Fade Margin. The theoretical calculations use assumptions and calculate availability based on a fixed rain rate, however in reality actual rain rate fluctuates greatly. When the rain rate increases, the BER increases in direct proportion. Other weather conditions have adverse affects on point to point links. This results in different outages in practice on a radio link, in comparison with the theoretical outages.

In order for some contingency in the radio link, and to ensure the link has a high practical level of availability, there is a fade margin incorporated in the planning and licensing of radio links. The fade margin ensures that even when the link is suffering a lot of fading, the received signal strength is equal to or higher than the threshold for approximately 99.995% of the time. Fade margin is typically in the range of 10 – 15dB. When the RF carrier signal received at the receive radio unit is only slightly faded, the total value of the fade margin is redundant and not necessary. However, to ensure link operation during high fading conditions, the fade margin needs to be maintained. Adaptive Modulation endeavours to utilise the fade margin when conditions allow it to.

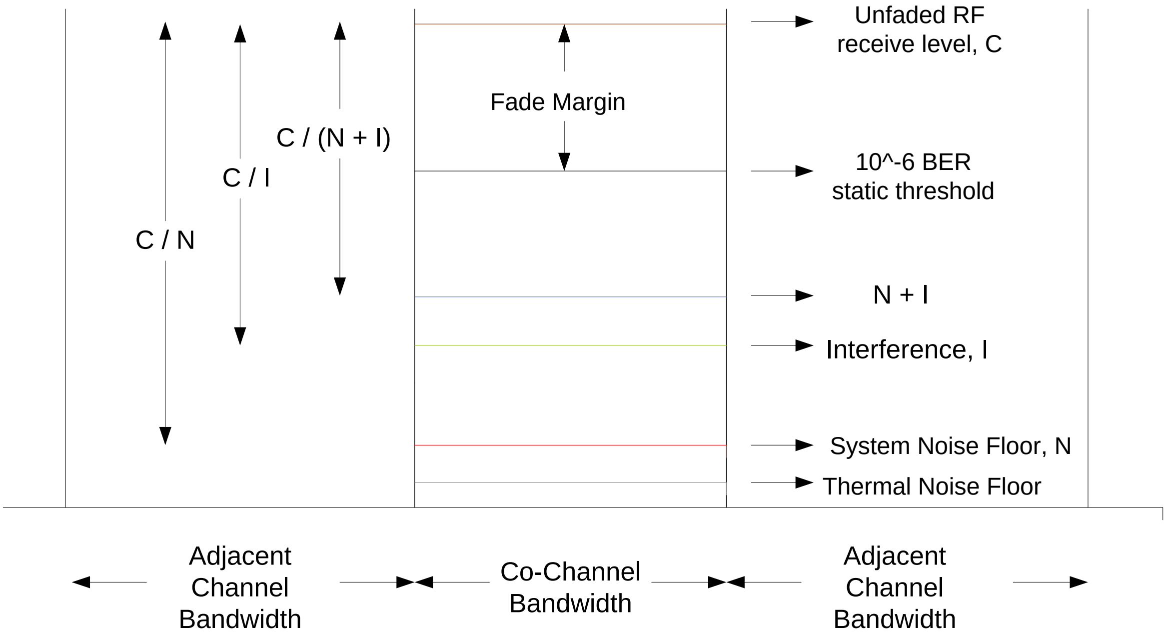

Figure 2: Unfaded RF receive level compared to noise and interference

Along with ensuring that a radio link has a suitable EIRP to maintain the availability for a given link, it is also necessary to ensure that a link does not suffer, or cause, harmful interference and a resultant degradation in services. Technical standards have been developed by ETSI[4] which define the required carrier to interference (C/I) ratios which must be adhered to in order to ensure mutual compatibility between fixed links.

The minimum C/I ratio which must be maintained between radio links varies according to which band the link is proposed to operate in, and is dependent on the capacity/modulation technique being deployed on this radio link. A C/I ratio exists for external co-channel links, and there is another C/I ratio which exists for external adjacent channel links. External links refer to other operators of radio links within the band; ComReg does not carry out intra-network interference calculations, as the onus is on operators to ensure that their own radio links do not cause harmful interference with other links belonging to their own networks. As one can appreciate, the C/I ratio is significantly higher for co-channel links than adjacent channel links, as the possibility of co-channel interference is greater and as such, a large C/I ratio must exist for co-channel links. An example of a C/I ratio is as follows; a PDH link in the 13GHz band, with a bandwidth of 3.5MHz and delivering a bit rate of 8 Mbit/s using 16QAM modulation scheme requires a co-channel C/I ratio of 30dB, and an adjacent channel C/I of ratio of-1dB. A visual depiction of this is shown in Figure 3.

[4] ETSI EN 301 217-2-2 V1.3.1 (2008-12) – Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2-2: Digital systems operating in frequency bands where frequency co-ordination is applied; Harmonized EN covering the essential requirements of Article 3.2 of the R&TTE Directive

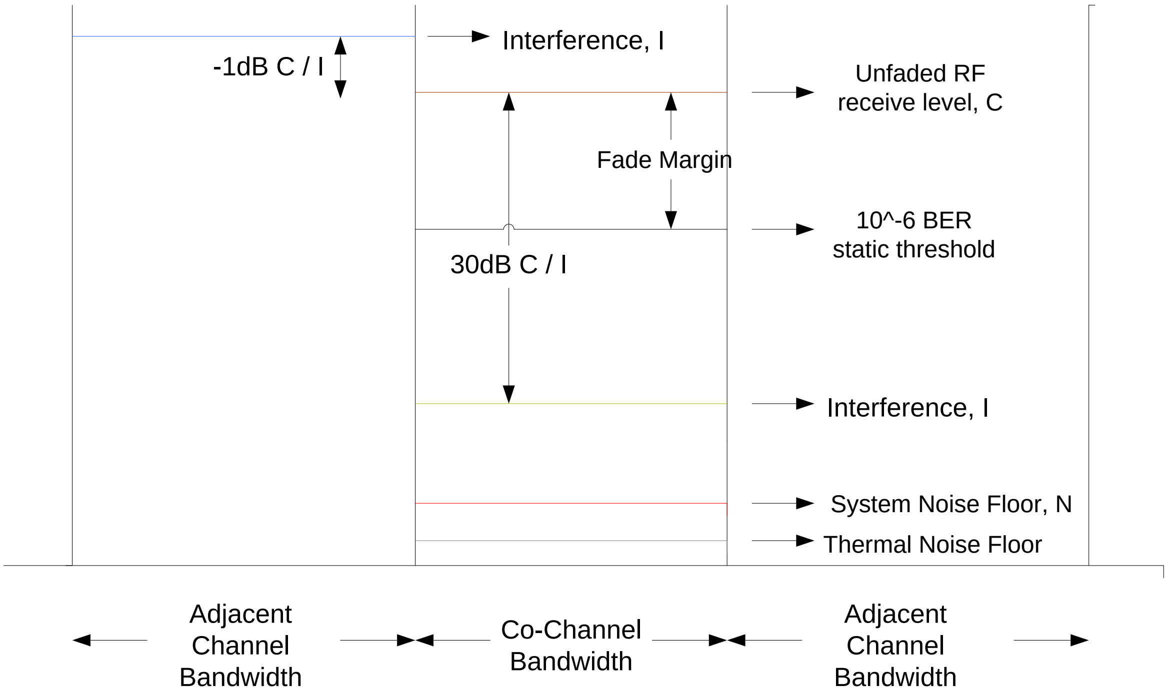

Figure 3: Necessary Carrier to Interference ratio for co-channel and adjacent channel

The minimum C/I ratio required increases as the order of modulation scheme increases. That is to say, a lower order modulation scheme (e.g. QPSK), requires a lower C/I ratio than a higher order modulation scheme (e.g. 64QAM). For a given channel bandwidth, a high capacity link requires more protection from potential interferers as it is more susceptible to increased and intolerable BER than a lower capacity link.

2.2 New licensing regime for ACM in terrestrial fixed links bands

It is apparent from Section 2.1 that there is potential for greater efficiency by utilising the fade margin. For the vast majority of the time, the RSL is significantly higher than the threshold value of the receiver, often 10dB greater. When this 10dB fade margin exists, it would be valuable to utilise it to increase throughput on a given radio link. As noted earlier, radio links in Ireland operate with a fixed modulation scheme. The proposed licensing regime would allow adaptive and differing modulation schemes on any given link to take advantage of the fade margin when possible. This would give rise to increased throughputs and more efficient use of spectrum.

Point to point adaptive modulation radio equipment exists, and this equipment allows for the radio link to take advantage of the fade margin to increase order of modulation and hence increase throughput. Figure 4 shows an example of RSL for a given radio link over a period of time.

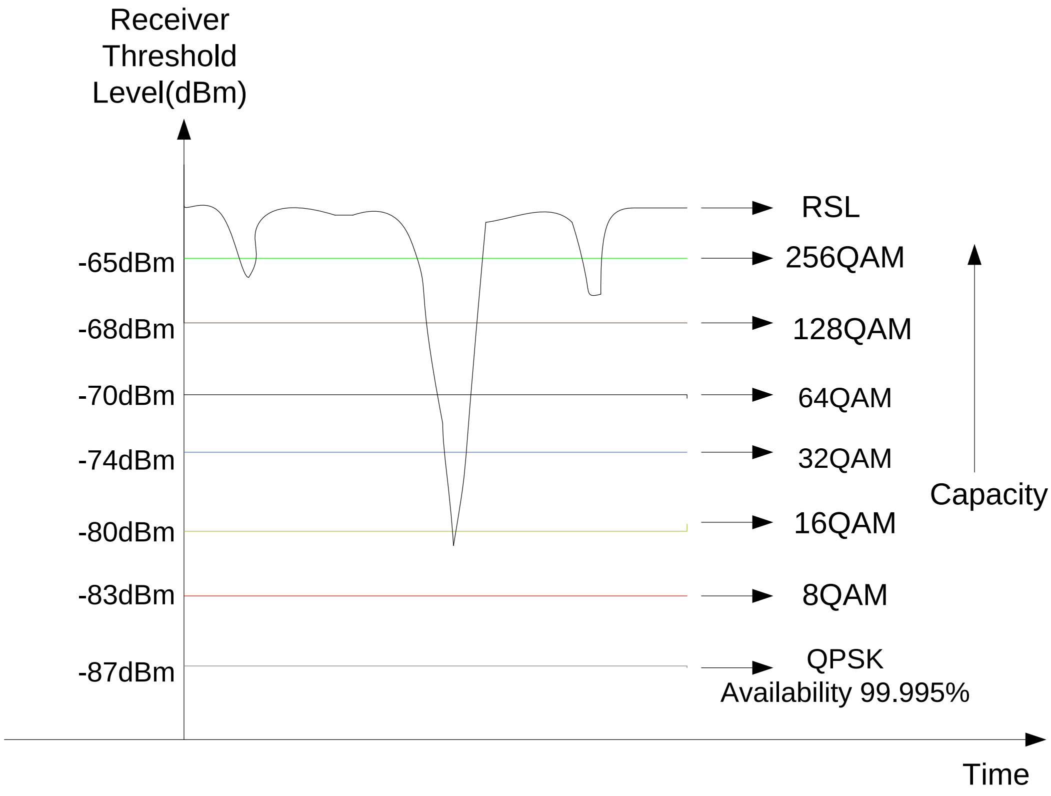

Figure 4: Varying RSL over time, and achieveable modulation schemes dependant on RSL

ComReg currently assigns and licences spectrum frequencies for use by point-to-point radio links with a specific modulation. So, for the example shown in Figure 4, it can be seen that if the fixed modulation scheme deployed for this link was QPSK, the RSL is always significantly higher than the QPSK threshold value. The difference between the RSL and the threshold is the fade margin. It can be seen from the given example in Figure 4 that the radio link could potentially operate with 256QAM for the vast majority of time by taking advantage of the large fade margin when it is present. However, with the current licensing regime this is not possible.

Deploying of ACM may result in CAPEX and OPEX savings. Smaller antennas are utilised which may reduce CAPEX and the cost of site rental ACM also provides a solution to the potential bottleneck and congestion problems in fixed link bands when new capacity intense technologies are launched on the market, e.g. WiMAX and Long Term Evolution ('LTE'). ACM allows for a higher achievable capacity for a given channel, reducing the number of channels needed per link and resulting in additional spectrum being available for licensing.

2.3 Next Steps

ComReg will permit the use of ACM in fixed microwave link bands and will incorporate ACM in its next version of the microwave point to point guidelines. This allows for new radio link applications to request the use of ACM equipment for its radio links, whilst also allowing for current licensees to amend current licences should they wish to deploy ACM.

This will allow for a radio link, as shown in Figure 4, to be operated at the highest order modulation scheme available at a particular time, in order to increase throughput on the given link when the fade margin allows, while maintaining the availability of the radio link. ACM equipment uses Forward Error Checking (FEC) in order to calculate the fading in the radio channel. The radio unit will operate with the highest modulation scheme available at that time, and will dynamically adapt the modulation scheme when conditions change. Adaptive modulation would allow for a radio link to use multiple modulation schemes, dependent on the RSL.

An ETSI standard[4] sets out the manner in which adaptive modulation and coding should be deployed, and ComReg will incorporate this into its licensing regime. In line with this standard, ComReg requires that a reference mode for a fixed link must be defined. This reference mode should be capable of delivering the core bit rate (high availability traffic), and utilising the fade margin when possible to increase the data rate (for lower priority traffic). An application for a fixed link using ACM must be for the minimum modulation scheme it will use on the link.

The RSL will be determined by the RSL of the system in reference mode, and this RSL will be used in assigning an EIRP which in turn will determine level of availability allowable for the given link. The C/I ratio used to protect the radio link will be determined by the C/I ratio defined for the reference mode.

At all times, the EIRP assigned to the system must be consistent and not vary from the value stipulated in its licence, even when there is a transition of modulation schemes and capacity. As stated in I.3.2 of ETSI EN 302 217-2-2 V1.3.1 - *"TX emission should not exceed that of the reference mode"*. In doing so, current licensed links and future links in bands, whether deploying ACM or fixed modulation technology, would not be adversely affected by a system deploying ACM in the same band.

The licence which ComReg will grant to an ACM system will include the modulation scheme and capacity of the reference system. These values will be indicative of the reference system nominated by the licensee, and these values will not describe the range of capacity and modulation schemes that the system can utilise. As previously mentioned, the EIRP outlined in a licence must be adhered to and this value cannot be exceeded at any time.

ComReg welcomes any comments or queries on the substance of this paper.