Marine DGNSS Availability and Continuity

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The maritime radiobeacon differential GNSS service in Europe has recently been reorganised with the aim of having at least two of the 162 stations serve each critical coastal location. Maritime administrations have now set specifications for the availability and continuity of the service. The paper analyses these requirements, noting incompatibilities between them. It proposes a method of predicting the performance of beacons, employing IALA standards. This takes into account each beacon's own availability, and propagation factors that include groundwave signal attenuation, interference, and skywave fading at night. Availability, continuity and coverage maps produced by the new programs are presented in the paper.

KEY WORDS

1. GPS.   2. Differential GNSS.   3. Marine radiobeacons.

1. INTRODUCTION. Differential Global Satellite Navigation Systems (DGNSS) employ the principle that the main sources of error in satellite navigation are consistent over substantial geographical areas. These errors can be corrected by using reference stations at known locations to measure the pseudorange errors of the signals received from the satellites. The reference stations then transmit corrections to users' receivers, which adjust their position measurements accordingly. The advantages of DGNSS are improved accuracy and enhanced integrity.

One of the oldest radio aids-to-navigation technologies, the marine radiobeacon, is widely employed to transmit DGNSS corrections for maritime users (Enge and Olsen, 1990; Enge and Ruane, 1986). In Europe and North America, several DGNSS beacons can generally be received simultaneously (IALA, 1999–1). This greatly enhances signal availability and continuity for the user.

IMO resolutions stipulate the minimum signal availability and continuity that should be provided at critical, and also at less critical, locations. This paper considers those requirements, together with other sources of availability and continuity specifications. We then take software designed to plot the coverage and performance of DGNSS radiobeacons (Last, Grant and Ward, 2001) and extend it to map the locations at which both individual beacons, and groups of beacons, meet these service standards. The diagrams presented in this paper are examples of the use of this

Table 1. Comparison of signal availability definitions.

Document	Includes		Availability requirement
	Ref station	Environment	
IMO (860)	√	√	99·8% Everywhere
IALA (815)	√	X	99·8% Critical areas
			99·5% All other areas
IALA (Guide)	√	√	None Specified
IALA (Draft Guide)	√	√	99·8% Critical areas
			99·5% All other areas
FRP	√	√	99·9% Critical areas
			99·7% All other areas
USCG	√	√	99·9% Everywhere
EMRF (App)	√	√	99·8% Everywhere

technique. The sets of beacons they illustrate are not necessarily precisely the same as those currently in operation.

2. DEFINITIONS OF AVAILABILITY. *Availability* is the percentage of time for which a signal at a location is usable. Being *usable* means meeting minimum criteria for coverage set out by the International Telecommunication Union (ITU) (ITU, 1997). In Europe, these criteria are that the field strength must be not less than 20 dBμV/m (or a higher figure specified by the national administration), and the signal-to-noise ratio (SNR) not less than 7 dB. In addition, no interfering signal may exceed a specified protection ratio that depends on the frequency separation between the signals from the interferer and beacon.

Included in these criteria are both deterministic and stochastic factors. The deterministic elements are the strengths of the groundwave-propagated signals received from the reference station and from any interfering stations. These strengths are constant and can be estimated using ITU data. The stochastic elements – those whose values exhibit random variations – are the strengths of the skywave components of the signals from the reference station and possible interfering stations, and also atmospheric noise. ITU data lets us predict at any time and place both their mean values and the magnitudes of their variations. For example, we customarily estimate the atmospheric noise level not exceeded 95% of the time (ITU, 1999).

The first task is to establish the signal availability requirement. We have reviewed the following documents: relevant current resolutions of the IMO (IMO, 2001; IMO, 2002); documents from the International Association for Marine Aids to Navigation and Lighthouse Authorities (IALA) (IALA, 2001), including changes IALA has proposed to IMO resolution A.815 (IALA, 2000); the current US Federal Radionavigation Plan (FRP) (USDoD/USDoT, 2001), and United States Coast Guard (USCG) documentation (USCG, 1993) (both only strictly applicable within the US); and recent proposals for changes to IMO documentation from the European Maritime Radionavigation Forum (EMRF) (EMRF, 2001).

Table 1 summarises the factors that each document takes into account in determining availability. Thus, all sources include the availability of the reference station (Ref Station). Most sources also include the deterministic and stochastic factors

listed above that characterise the environment in which the receiver operates (Environment). These factors are not always identified explicitly, however. Rather, the document will simply state, or imply, that the availability specification it proposes applies across the whole of the beacon's coverage. Clearly, this must include the regions lying out along the coverage boundary where the field strength and signal-to-noise ratio are at their lowest due to the effects of the environment factors. We decided to incorporate both the reference station and environmental factors into our availability model, thus complying with the requirements of the most demanding specifications.

The *Availability Requirement* column of Table 1 shows the considerable variation in the numerical values specified in the various documents. IMO, USCG and EMRF set a single value, applicable everywhere. We chose, however, to employ the IALA definition, which is a development of the requirements specified in IMO Resolution A.815(19). IALA have two requirements: 99·8% availability in high risk areas, and 99·5% in areas of lower risk served by just a single beacon. An amendment to the high-risk requirement is required when dealing with US radiobeacons, since the US specification is tighter.

3. ESTIMATING BEACON AVAILABILITY. In an environment in which a number of factors are stochastic, availability is probabilistic. However, although several of the documents cited give examples of such calculations, none of those examples takes fully into account all deterministic and stochastic factors. We decided, therefore, to develop new software to calculate availability values. This will operate in accordance with our decisions both to take reference station and environmental factors into account and to employ availability criteria of 99·8% or 99·5%.

The stochastic events with which we are concerned are the beacon's own periods off-air, a rise in atmospheric noise, a rise in skywave-borne interference, and self-fading. All deterministic events have already been taken into account in predicting the coverage; since we estimate availability within the coverage area only, they do not affect the results.

Clearly, we require a statistical approach to model the effects of multiple stochastic elements. Poppe has shown that skywave field strength has a Gaussian probability distribution (Poppe, 1995). She provides data from which the mean and standard deviation values of the skywave components of both the wanted beacon and any interfering signals can be calculated. In a similar way, the means and standard deviations of the atmospheric noise can be obtained from ITU noise data (ITU, 1999). Atmospheric noise, however, has a two-sided distribution: both sides are approximately Gaussian, albeit with different standard deviation values. Since we are interested solely in the case where excessive noise causes loss of availability, we need to take into account one side of the distribution only. Thus, we can treat atmospheric noise as being Gaussian, with a single standard deviation value.

Poppe has also computed the effect of self-fading on the resulting field strength of a beacon. She developed a technique for calculating this effect given a known ratio between skywave and groundwave signal strengths. Nominally, the 95% fading curve is employed when predicting coverage. However, by calculating the difference in the fading between this 95%-ile curve and the 50%-ile curve (Δfade), the standard

deviation can be estimated. Assuming a Gaussian distribution, the following equation applies:

$$\sigma = \frac{\Delta\text{fade}}{1\cdot 65}, \tag{1}$$

where σ is the standard deviation, Δfade the difference between the 95% and 50% curves, and $1\cdot 65$ is the constant that relates the 95% and standard deviation of a Gaussian distribution.

By using the mean and standard deviation values of both the wanted beacon's skywave signal and the atmospheric noise, the probability of the SNR exceeding the 7 dB minimum can be calculated. In the same way, we can compute the probability of the signal-to-interference ratio (SIR) exceeding its protection ratio from knowledge of the mean and standard deviation of the strongest interferer's skywave signal.

Let X_s be the strength of the beacon signal and X_n be the strength of the atmospheric noise. As explained above, both X_s and X_n are normally distributed random variables, i.e., $X_s \sim N(\mu_s, \sigma_s^2)$ and $X_n \sim N(\mu_n, \sigma_n^2)$. In our method, a new random variable b is defined to be the strength of the signal after taking out the atmospheric noise, i.e., $b = X_s - X_n$. The new variable b is also normally distributed with mean $\mu_s - \mu_n$ and variance $\sigma_s^2 + \sigma_n^2$; $b \sim N(\mu_s - \mu_n, \sigma_s^2 + \sigma_n^2)$. Therefore, to estimate the probability that b exceeds a specified constant c (the SIR or SNR floor), we use

$$\Pr(b \geqslant c) = 1 - \Phi\left(\frac{c - (\mu_s - \mu_n)}{\sqrt{\sigma_s^2 + \sigma_n^2}}\right), \tag{2}$$

where Φ is the standard normal cumulative distribution function, given by:

$$\Phi(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{\frac{-t^2}{2}} dt. \tag{3}$$

Using this equation at each location, the probabilities of exceeding the SNR and SIR floors are calculated, and thus the beacon's service availability.

The beacon's own on-air availability is normally monitored and recorded by the administration responsible for it. In this paper, we will employ an example value of 99·5% suggested by IALA (IALA, 2001). The three probabilities of failure (beacon, fading and noise) are then combined using:

$$\text{Avail}_{\text{signal}} = \prod_{i=1}^{n} (1 - P(\text{event } i \text{ occurring})), \tag{4}$$

where P(event i occurring) is the probability of occurrence of each of n events, three in this case. The use of this equation gives us a single availability figure. Note that close to the beacon where its field strength is greatest events related to propagation have relatively little effect and $\text{Avail}_{\text{signal}}$ is virtually the same as the beacon's own availability.

In locations at which more than one beacon provides coverage simultaneously, having a choice of beacon results in greatly enhanced availability, provided the failures of the various candidates are independent. We have demonstrated by means of a measurement programme that the various failure mechanisms are indeed essentially

uncorrelated (Grant, 2002). The final availability figure at such locations is therefore:

$$\text{Availability} = \prod_{i=1}^{n} (1 - \text{Avail}_{\text{signal}_i}), \tag{5}$$

where $\text{Avail}_{\text{signal}_i}$ is the availability of the signal from beacon i and n is the number of beacons providing simultaneous coverage.

4. THE TWO-YEAR STANDARD. The IALA specification requires availability to be measured over a two-year period. The IALA example figure for the beacon's own availability, 99·5%, makes no distinction between day and night operation. However, we have chosen to build into our model the assumption that scheduled maintenance is carried out by day only, as is generally the case in practice. Thus, although the overall beacon availability remains at 99·5%, the daytime value falls to 99·3% while the night-time value rises to 99·6%. Conducting scheduled maintenance by day results in a significantly higher overall availability since it increases the availability of the beacon itself at night, the time when availability is more likely to be lost to propagation factors. Figures 1 and 2 present the results obtained using these assumptions. Figure 1 shows the daytime availability provided by the 16 beacons of the United Kingdom and Ireland. Across the whole of this light grey region – i.e. all coastal waters – the higher availability requirement of 99·8% over two years has been met. Figure 2 shows the corresponding night-time plot. The radiobeacons' coverage areas are now reduced by self-fading, interference, and an increase in atmospheric noise, but do benefit from the higher on-air availabity of the beacon itself. Again, areas coloured light grey receive a service for 99·8% of the time. In areas coloured dark grey, the lower 99·5% requirement has been met. We see that the majority of coastal regions still enjoy the higher availability at night, while most of the remainder get the lower standard.

Now we wish to combine these two plots into a single availability plot. We have estimated that, across the European Maritime Area (EMA), the average percentage of the two-year period when daytime radio conditions apply is 43%; night-time conditions apply for the other 57%. We thus combine the day and night availability figures, weighting each in accordance with these percentages, to create two-year availability results for the 16 beacons of the United Kingdom and Ireland. Figure 3 shows the result. Much to the delight of the system's administrators, the majority of the coastal regions enjoy a service that meets the 99·8%, 2-year, standard. Most other regions get a service that meet the lower 99·5% standard. Where this standard does not appear to be met, it is in fact achieved once the additional beacons on the continent are taken into account. The model was now employed to calculate the two-year availability of the service provided by all 162 beacons of the EMA (Figure 4). Again, the majority of coastal areas are provided with a service available 99·8% of the time. This includes the important coastal areas of the North Sea, the English Channel and the north coast of the Mediterranean Sea. The majority of the remaining coastal regions get a service that meets the lower 99·5% requirement.

5. DEFINITIONS OF CONTINUITY. The authorities who specify availability standards also set criteria for continuity, as summarised in Table 2. Again,

Figure 1. Daytime service availability provided by the 16 beacons of the United Kingdom and Ireland. Light grey = 99·8%, Dark grey = 99·5%.

there are substantial differences between their requirements! IMO sets a single continuity figure, applicable everywhere and at all times. IALA and EMRF require 99·97% in high-risk areas, and 99·85% for areas of lower risk and single beacon coverage. However, an exception to this is IALA's proposal for revision of the IMO resolution A.815, which agrees with that IMO resolution. The FRP standard for continuity (they call it *reliability*) is that the *number of outages per site will be less than 500 in one million hours of operation* (USDoD/USDoT, 2001). As a continuity requirement this is vague, since there is no indication as to the minimum duration of an outage. Similarly, the USCG specifies the reliability of the system in terms of a number of manoeuvres of different durations, and the corresponding numbers of outages allowed per million hours. But, again, no indication is given to what constitutes an outage.
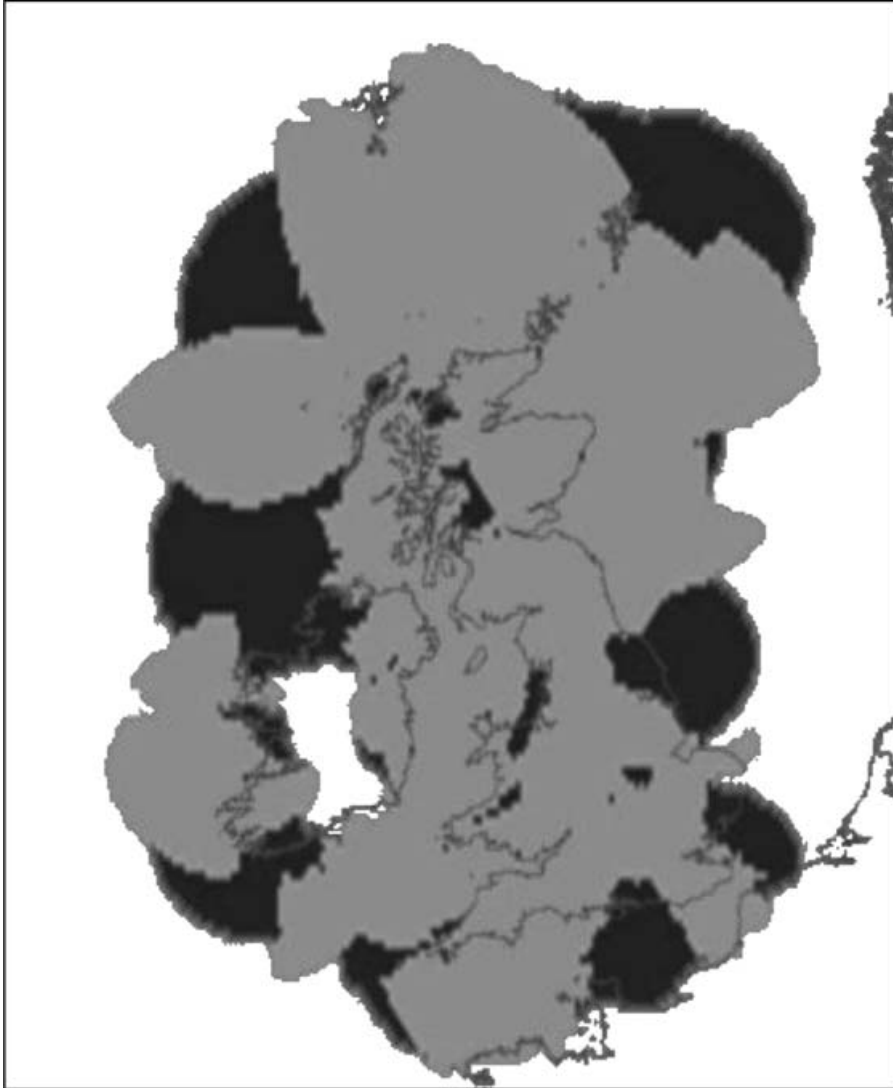
Figure 2. Night-time service availability provided by the 16 beacons of the United Kingdom and Ireland. Light grey = 99·8%, Dark grey = 99·5%.

In our judgement it is appropriate to employ the 99·97% and 99·85% IALA values: they are world values, rather than US national ones, and they represent the latest development of the IMO requirements. IALA also make it clear that they calculate continuity over three hours, as opposed to 1 year or 1 million hours (IALA, 2000). Since continuity is to do with providing guidance for the whole of a manoeuvre such as port entry or docking, this 3-hour definition appears appropriate, given that such manoeuvres typically take three hours or less (IALA, 2001).

As with availability, stochastic factors are the only ones that affect continuity. These are the beacon service, atmospheric noise, self-fading, and skywave-borne interference.

Figure 3. Two-year service availability provided by the 16 beacons of the United Kingdom and Ireland. Light grey = 99·8%, Dark grey = 99·5%.
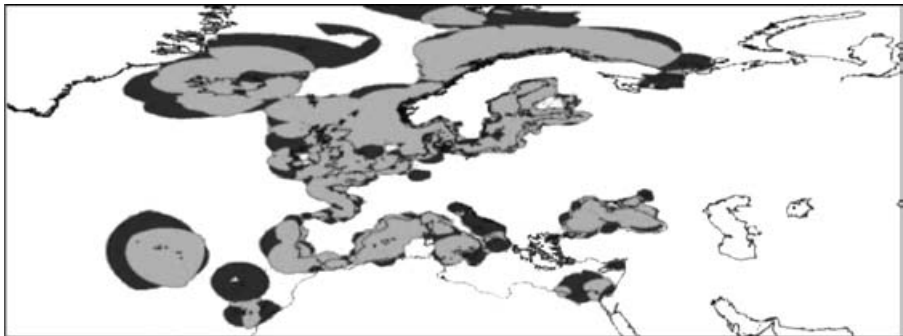

Figure 4. Two-year service availability provided by the 162 beacons of the EMA. Light grey = 99·8%, Dark grey = 99·5%.

Table 2. Continuity specifications and periods.

Document	Continuity requirement	Calculation period
IMO (860)	⩾99·97% Everywhere	1 year
IMO (815)	⩾99·97% Everywhere	1 year
IALA (815)	⩾99·97% High risk areas	3 hours
	⩾99·85% All other areas	
IALA (Guide)	⩾99·97% Everywhere	1 year
IALA (Draft Guide)	⩾99·97% High risk areas	3 hours
	⩾99·85% All other areas	
EMRF (App)	⩾99·97% Port areas	3 hours
	⩾99·85% Coastal areas	
EMRF (815)	⩾99·97% High risk areas	3 hours
	⩾99·85% All other areas	
FRP	The number of outages per site will be less than 500 in one million hours of operation	

USCG	Manoeuvre Category: Reliability
	   <140 s: 2000 Outages/Mh
	   140–280 s: 1000 Outages/Mh
	   280–560 s: 50 Outages/Mh	

6. BEACON CONTINUITY. A beacon's continuity may be calculated in accordance with a method given in the IALA guidelines (IALA, 1999–2):

$$\text{continuity} = 1 - \left(\frac{\text{CTI}}{\text{MTBF}} \right), \qquad (6)$$

where CTI is the continuity time interval (three hours in this case), and MTBF the mean time between failures, in hours. When calculating beacon continuity, it is assumed that there are no scheduled outages within the duration of the manoeuvre. This assumption is based on the fact that scheduled outages are announced in advance. Thus, no manoeuvre that depends critically on the system should be commenced if the system is forecast to be unavailable for any part of its duration. Continuity failure occurs where a manoeuvre has been commenced and then cannot be completed because the system fails. Using the example from (IALA, 2001) and assuming the lowest beacon on-air availability of 99·5%, the corresponding MTBF calculated would be approximately 1946 hrs. This number would be the same under either day or night conditions. From this we calculate a beacon continuity of 99·85%.

As with availability, the probability of a failure due to a rise in atmospheric noise, skywave interference or self-fading decreases the closer the receiver is to the beacon. Continuity thus behaves in the same way: near the beacon, the beacon's own continuity dominates.

6.1. *Atmospheric noise*. Calculating the effect of atmospheric noise on continuity is difficult. Even knowing the standard deviation and mean value of atmospheric noise does not tell us about its effect on continuity. We can establish the percentage of time for which atmospheric noise will cause the signal to be unavailable, but we have no information regarding the distribution of the failures in time. For example, we do not know the MTBF. Thus, we cannot use this information directly to compute the effect of atmospheric noise on continuity. A different approach is required.
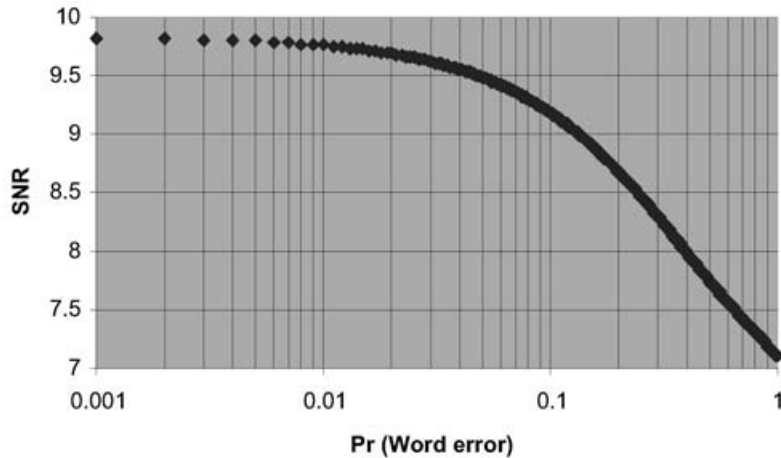
Figure 5. Probability of word error as a function of SNR.

Atmospheric noise consists of two parts: random spikes of relatively high intensity, and continuous background noise of lower intensity. It is the high-intensity random spikes that predominately disrupt the service. To calculate their effect on continuity, one needs a measure of the mean time between spikes and thus of the relationship between MTBF of the message and SNR. To *measure* these factors with a high level of confidence would require data to be measured over a long period. No such set of data appears ever to have been recorded. However, indirect evidence is available from Poppe's research (Poppe, 1995). Poppe studied atmospheric noise extensively and recorded the variation of word error rate (WER) with SNR shown in Figure 5. Poppe obtained this data in a quiet location using a transmitter (with negligible propagation effects) and a conventional differential beacon receiver. Noise was true off-air atmospheric noise. Her measurements show a fairly high probability of word error at an SNR of 7 dB, the ITU threshold, whereas in practice receivers work reliably at this SNR. However, once SNR had risen by just 2 dB, to 9 dB, Poppe's errors had become rare. Thus, Poppe's results appear sufficiently accurate to give us a reasonable estimate of the effects of atmospheric noise on continuity. We can use Poppe's word error rate (WER) data to calculate the probability of the service's becoming unavailable due to noise. The probability of a single message's being received is:

$$\Pr(\text{success}) = [1 - \Pr(\text{word error})]^{W}, \tag{7}$$

where Pr means probability, and W is the number of words in the message (7 in the case of a Type 9-3 message). Figure 6 plots this probability of message success against the signal-to-noise ratio.

Now let us consider the probability of missing successive messages. With Selective Availability (SA) set to zero, the failure criterion is now set by the maximum time-to-alarm of 10 s (Grant and Last, 2001). Since each Type 9-3 message takes 2·1 s to transmit, it would be necessary to miss four messages in succession for a failure to occur. The probability of this happening can be calculated using the results from Figure 6:

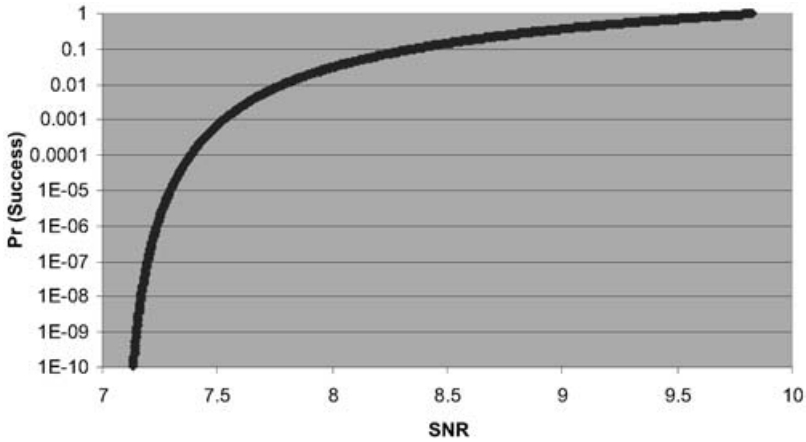$$\Pr(\text{failure}) = (1 - \Pr(\text{success}))^{4}. \tag{8}$$

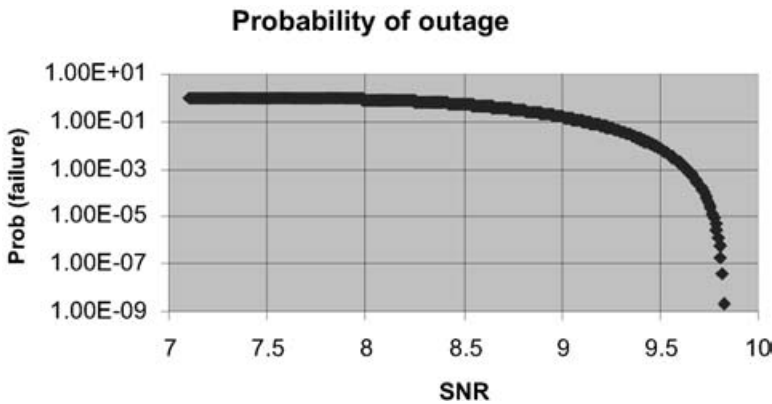Figure 6. Probability of receiving a single message successfully as a function of SNR.

Figure 7. Probability of alarm failure as function of SNR.

Figure 7 plots this probability against signal-to-noise ratio. The probability appears to be extremely low in areas where the SNR is greater than 9 dB. We have already established that Poppe's 9 dB is roughly equivalent to the ITU minimum SNR of 7 dB. Thus, we now know the probability of missing four successive messages and failing to meet the time-to-alarm criterion; this gives us the probability of continuity failure we required.

6.2. *Skywave interference.* Like atmospheric noise, skywave interference can affect the continuity of the signal. Simple measures of statistical distribution are again of no use in estimating continuity, since we need to know the time between failures and we lack data records from which to compute MTBFs. In practice, such measurements would be very difficult to make, since it would be necessary to distinguish between the effects of skywave interfering signals and those of atmospheric noise. The approach we take is to assume that, at a given SNR, the probability of an error due to the noise being skywave interference is the same as if the noise were atmospheric noise. This allows us to employ again the atmospheric noise

Figure 8. Daytime 3-hour service continuity for the 16 beacons of the UK and Ireland. Light grey = 99·97% (critical areas requirement met), Dark grey = 99·85% (other areas requirement met).

continuity/SNR relationship (Figure 7). Given the rapid change of error rate over just a few dB of SNR, this approximation is likely to give acceptable results.

In the case of skywave interference, however, the lowest SNR value that will ever be encountered within the coverage area is 15 dB, the edge-of-coverage limit. Thus, whilst there is undoubtedly a finite probability of message failure due to skywave interference, it will be extremely small, and insignificant in comparison with the other stochastic factors. The result of our analysis, therefore, has been to demonstrate that we do not need to take skywave interference into account in computing continuity.

6.3. *Self-fading.* Self-fading, due to the interaction between the deterministic groundwave signal and the stochastic skywave signal, gives a stochastic result. We are again interested in the time interval between occasions when it disrupts the service. Once more, the experimental data to establish the relationship is not available. We have adopted the following method of allowing for the effect of signal fading on continuity. When calculating the SNR and SIR values used to determine the continuity figure, we employ the reduced beacon field caused by fading. The value we use is the strength exceeded 95% of the time (Poppe, 1995). This 95%-ile figure is, of course, the same value as is used to establish the outer edge of the beacon's coverage.

7. CONTINUITY RESULTS. Figures 8 and 9 show the continuity results, calculated using the method developed in Section 6, for the 16 beacons of the

Figure 9. Night-time 3-hour service continuity for the 16 beacons of the UK and Ireland. Light grey = 99·97% (critical areas requirement met), Dark grey = 99·85% (other areas requirement met).

United Kingdom and Ireland. The conventions used in the figures are the same as for availability: light grey shows where beacons provide the higher level of service continuity (99·97%) and dark grey the lower standard (99·85%). Meeting the higher standard requires at least two beacons to provide coverage simultaneously. Just a single beacon is sufficient to meet the lower standard.

Figure 8 shows that by day, as with availability, meeting the higher continuity requirement is not a problem. In all coastal and inland locations, sufficient beacons provide simultaneous coverage to allow the 99·97% requirement to be easily met.

At night, in contrast, with the reduction of beacons' coverage areas due to self-fading and the rise in skywave interference and atmospheric noise, we see substantial shrinkage of the areas in which both the standards are met (Figure 9). Thus, fewer coastal areas receive a 99·97% continuity service. However, in all other coastal regions the lower 99·85% is achieved.

Figures 10 and 11 show the daytime and night-time continuity results, respectively, for the whole EMA. Again, by day, all coastal regions enjoy the higher 99·97%
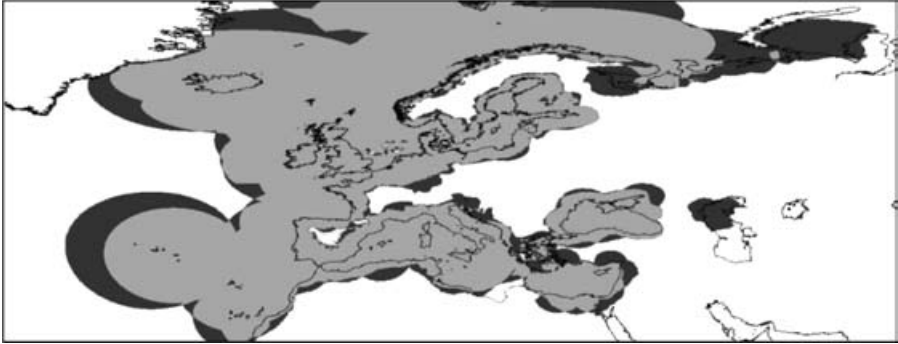
Figure 10. Day-time 3-hour service continuity provided by the many beacons of the EMA. Light grey = 99·97% (critical areas requirement met), Dark grey = 99·85% (other areas requirement met).
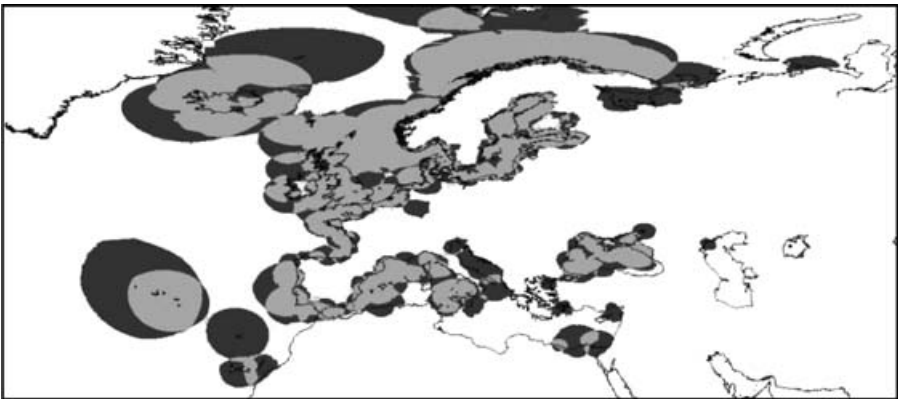

Figure 11. Night-time 3-hour service continuity provided by the many beacons of the EMA. Light grey = 99·97% (critical areas requirement met), Dark grey = 99·85% (other areas requirement met).

continuity requirement. Figure 11 shows the now familiar night-time reduction. But in most coastal regions the 99·97% standard is achieved, with the other areas getting the lower-standard service.

8. SERVICE STANDARDS. The service standards we have now calculated at each location include three different sets of limiting factors: coverage criteria, availability standards and continuity standards. For a service to be satisfactory, all three must be met. Taking the 16 beacons of the United Kingdom and Ireland, we have compared the new continuity results with the availability results computed earlier. We found that everywhere the service met the availability requirement, it also met the continuity one, but not *vice versa*; that is, availability criteria are the more stringent of the two. Thus, the areas in which all three criteria are met are the same as those shown in the availability plots, Figures 1 and 3. We conclude that, by day, all coastal regions of the EMA are provided with a service that meets the higher of two sets of standards for coverage, availability and continuity. By night

Figure 12. Night-time service meets coverage, availability and continuity requirements. Light grey = 99·97% (critical areas requirement met), Dark grey = 99·85% (other areas requirement met).

(Figure 12), when coverage areas are reduced, the majority of coastal regions are still provided with a service that meets all the more stringent requirements. In those regions where these conditions are not met, the service nevertheless meets the requirements for areas of low-risk and single beacon coverage.

9. CONCLUSIONS. This paper has demonstrated the processes involved in predicting the availability and continuity of a maritime radiobeacon DGNSS service. It has shown that predicting availability is a complex process involving many elements. A novel approach is described and employed for the first time. It combines statistically the mean and standard deviation values of the various stochastic elements in order to calculate the availability of each beacon and of the overall service provided by multiple beacons. This approach employs data on the statistical distributions of atmospheric noise and skywave interference from referenced

material. A quantitative understanding of the effect of self-fading has been derived by expanding the work of Poppe.

Then, for the first time continuity has been analysed. We see that the same events that affect availability, affect continuity. Each of these events has been examined. Without knowing, or being able to calculate, an MTBF for each SNR, it is impossible to calculate precisely its effects on continuity. But an alternative approach has been pioneered, based on the work of Poppe. Her research has shown us the dependence of word error rate (WER) on signal-to-noise ratio. From this we have developed a way of estimating the probability, for a particular SNR, of missing a message. We then define a failure as not receiving four consecutive messages. Using this approach we have calculated the probability of such a failure and hence its effect on continuity, as a function of SNR. This has been done for atmospheric noise and the process repeated for skywave interference. However, the latter is shown to have a negligible effect of continuity. Self-fading is taken into account by employing the night-time 95%-ile field strength values in determining SNR and SIR ratios. In this way, continuity values are estimated and the results for Europe compared with the international standards.

For the first time, it is now possible for administrations, service providers and other bodies to establish and plot those areas within which the marine radiobeacon DGNSS service meets all the standards: coverage, availability and continuity. The results show where beacons should provide a safe and reliable service.

ACKNOWLEDGEMENTS

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