■ White Paper

Communications at the battle of Arnhem: A modern day technical analysis

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Solutions in Radiocommunications

Introduction

It is well documented that communications during the Battle of Arnhem were difficult. From experience during previous campaigns using the proposed equipment, they were predicted to be difficult. They did however appear more problematic than expected with some commentators claiming an almost total communications breakdown. The reasons for this claimed failure are the subject of significant myth and supposition documented in many books. This paper reports on a project that aimed to quantify one area not yet covered – radio propagation – and asked (and answered) the question "should they have been able to communicate?" Once this is know, others can comment on whether they were able and hence comment on the difference between plan and execution.

The approach taken was simulation. Both command and artillery nets on Day 1 (17 September 1944) and Day 2 at Arnhem were modelled and compared one with the other. A conclusion of the work showing the likelihood of communications success is reported here for each path from Division to Brigade and between Brigades.

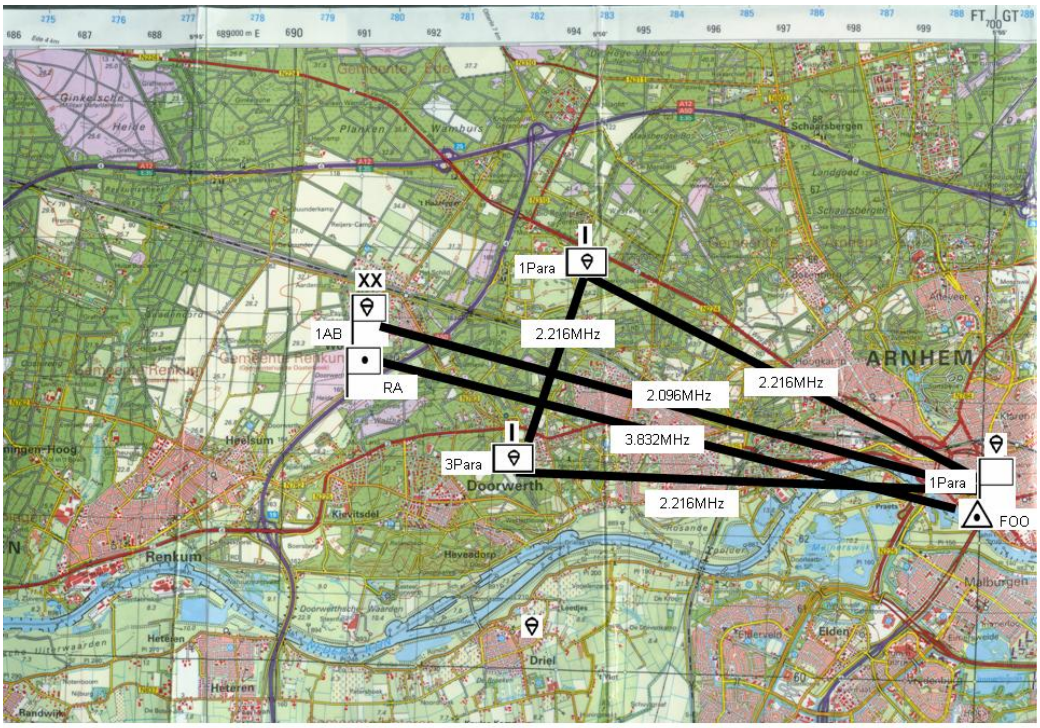

Figure 1: Command and Artillery Nets, Day 1, September 17th 1944

Equipment

Two equipments were in use at Arnhem – the vehicle mounted or trek cart carried Wireless Set No. 22 and the man-portable Wireless Set 68. Technical parameters for these two main radios were obtained[1]. Both used 12 foot long vertical rod antennas. They differed principally in RF output power – the 22 Set gave 1 Watt and the 68 Set, 0.25 Watt – resulting in a 6dB advantage wherever the 22 Set was used.

Signals Plan

The signals plan[2] showed several nets with associated frequencies. Initially the Divisional command net provided communications between the 1 Airborne Division dropping zone Zulu where the Division initially set up HQ and 1 Parachute Brigade on the bridge over one arm of the Rhine at Arnhem (Figure 1)[3] The path length here is 9.35km or just over 6 miles. On the second day the Div HQ moved to the Hartenstein Hotel near Oosterbeek (Figure 2). The main path dropped to about 6.6km or just over 4 miles. 1 Para were joined by 4 Para at dropping zone Yankee to the north west of the town. The path from Div HQ to 4 Para Brigade is shown and is around 8.6km or 5.7 miles.

The Battalion nets from Brigade HQ on the bridge have been omitted from the study since the path lengths were somewhat less than that to Div HQ – and therefore assumed to have had reliable communications on 2.692MHz using No. 68 Sets.

The artillery were reported to have communications both during Day 1 and Day 2 and these nets were used to pass some Divisional command traffic in the supposed absence of their own links. To complete the picture these additional nets are also shown. In the artillery nets the main link is from the Forward Observation Officer on the bridge co-located with the Brigade to Div HQ initially at the drop zone and then the next day co-located with Div HQ at Hartenstein Hotel. The path lengths of these artillery links were 9.35km and 6.6km respectively as noted above. The artillery HQ was in the grounds of the hotel in a dug-out. The net diagram also shows the battery net between Light Regt. HQ and two of the three artillery batteries. Radios used for all artillery links were No.22 Sets. The addition of the lower link back to No. 3 Battery from the Officer Commanding 3 Battery who was located on the bridge should also be noted. This was a 'private' link and was reported to have supported significant command traffic.

Antennas

The Divisional communications at Arnhem used ground wave and all antennas were vertical whips. There are several facets of the short vertical whip that have been considered in the work reported on here. They:

- Were short compared to the wavelength and hence would be difficult to match to [4]
- Needed good coupling to ground to avoid high Earth resistance losses [5]
- Had a significant null towards the horizon in their vertical response[6]
- Were short and hence of low capture aperture in turn making them inherently lossy

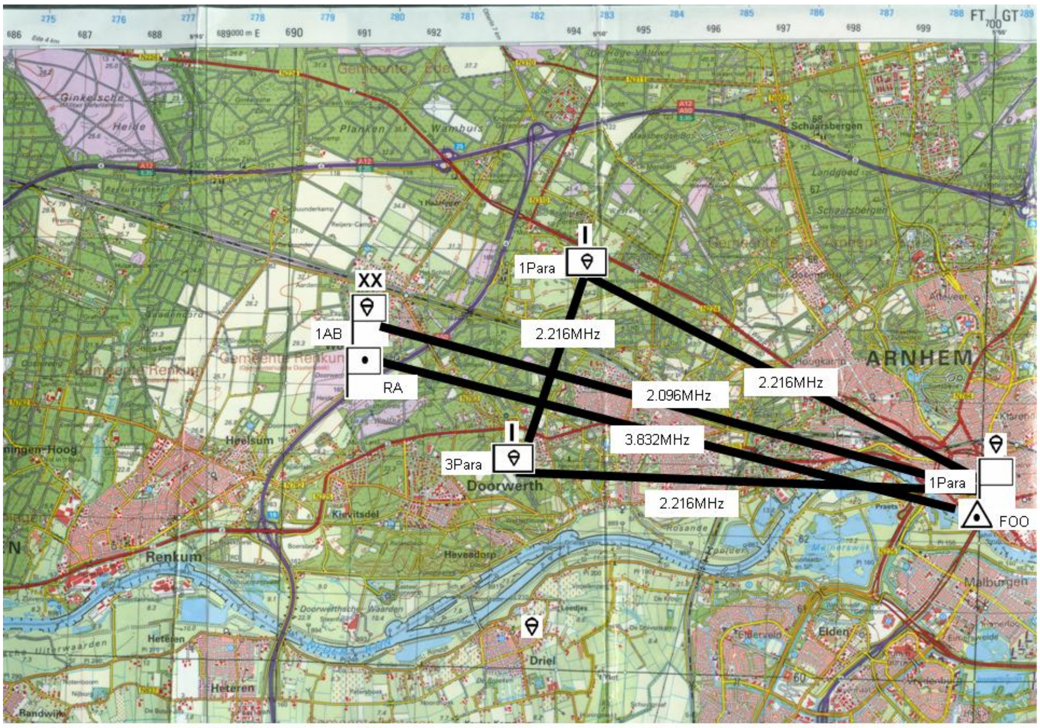

Figure 2: Command and Artillery Nets, Day 2, September 17th 1944

If used with an adequate Earth coupling over perfect ground or with a good counterpoise Earth losses and the vertical response null could be reduced. In the real application of Arnhem however, there can be no dispute - it was certainly a lossy antenna. During the project no evidence was found to suggest that the antenna had ever been characterised and so the project had to look at another means of estimating just how lossy the antenna was. The only way forward was to look at similar structures used in modern equipment in the hope that modern antennas had been defined. The antenna coming close is the whip antenna used by the PRC320 Clansman manpack. This is specified as having a loss to the horizon of –22dBi at 2MHz with a gain curve showing a rise in efficiency towards 4MHz. Considering this and the evidence above a figure based on -22dBi was assumed.

Minimum Signal to Noise Ratio

Typically military planning is conducted assuming a 13dB signal to noise ratio [7]. This is the modern planning minimum. A good signaller could work a link down to 6dB but the link quality would be poor forcing high repetition and error. For the purposes of this study a minimum of 10dB minimum was assumed defining the limit of useful communications.

Noise Floor

Environmental noise has a huge bearing on HF path performance. Table 1 shows the signal power needed (the receiver threshold in its environment) for a 10dB signal to noise ratio considering the ambient noise power. A noise environment in 1944 somewhere between today's 'rural' and 'suburban' has been assumed [8].

These values of received signal were used as the receiver threshold in all budget calculations in the project.

Path Budget

The path budget defines the maximum permissible propagation loss available for the equipment and antennas used. If that budget is exceeded the link would not have provided the communications required.

The maximum permissible propagation loss has been calculated for the 22 Set as 81dBi at 4MHz dropping to a more constrained figure of 70dBi at 2MHz. For the 68 Set this is 75dBi at 4MHz falling to 62dBi at 2MHz.

Results and Probability of Comms

Each of the paths with each of the associated parameters has been analysed using HTZ Warfare [9]. This software in turn used

Frequency	Noise Power Received	Received Signal Needed
2MHz	-74dBm	-64dBm
3MHz	-78.5dBm	-68dBm
4MHz	-81.6dBm	-72dBm

Table 1: Development of Receiver Thresholds

ITU-R Recommendation P368-7 – Ground Wave Propagation Curves for Frequencies Between 10kHz and 30MHz. Appropriate values of ground conductivity and relative permittivity which govern ground wave propagation at these frequencies were used. The recommendation expresses path length in terms of path loss for various frequencies, ground conductivity and relative permittivity[10]. Table 2 shows the summary of paths versus predicted path loss. It also shows the maximum permissible loss and the two can be compared to yield a margin. If the predicted loss is less than the permissible loss (giving a positive margin) the path will work. If the reverse is true the path will not work.

The probability of communications is a judgement based on the margin available. We can assume from knowledge of the prediction model and the potential for error in the antenna characterisation that that the RMS aggregated error in the prediction is high at around 8dB. Assuming that errors result in a normally distributed error curve, a zero or very low margin of up to 3 or 4dB will result in a probability of communications around 50-60%. Given a margin of more than 10dB we might assume a probability of around 90% with values of margin versus probability giving a greyscale between. This thinking has been reflected in the categorisation of Low, Medium and High Probability. To achieve a high probability, a margin of over 10dB is needed in turn giving a 90% chance that the path would have worked during the battle.

Conclusions

On Day 1, 17 September 1944, the Division HQ located at the drop zone some 9km from the bridge was too far away to provide reliable communications to the Brigade HQ on the bridge. Although the artillery link over the same path to the 1 Bd FOO did have a distinct advantage in frequency (having lower noise and more efficient antennas) the higher path loss counteracted any benefit rendering this also of low communications probability. It was only when the Division HQ moved to the Hartenstein Hotel that this advantage came into its own potentially providing a more robust link.

Since the Brigade net on Day 1 used 68 Sets over long paths of around 6.5km, the probability of communications between 2 Para on the bridge and 1 Para and 3 Para was also low.

Day	Path	Station A	Station B	Equipment	Frequency	Predicted Path Loss	Maximum Permissible Loss	Margin	Probability of Comms
17-Sep	Command	Division HQ	Brigade HQ	22 Sets	2.096MHz	64dBi	70dBi	6dB	Medium
	Artillery	HQ RA	1 Bde FOO	22 Sets	3.832MHz	77dBi	81dBi	4dB	Low
	Command	1 Para	Brigade HQ	68 Sets	2.216MHz	59dBi	62dBi	3dB	Low
	Command	3 Para	Brigade HQ	68 Sets	2.216MHz	59dBi	62dBi	3dB	Low
	Command	1 Para	3 Para	68 Sets	2.216MHz	46dBi	62dBi	16dB	High
18-Sep	Command	Division HQ	Brigade HQ	22 Sets	2.096MHz	56.5dBi	70dBi	13.5dB	High
	Command	Division HQ	4 Para	22 Sets	2.096MHz	71dBi	70dBi	-1dB	Low
	Artillery	HQ RA	1 Bde FOO	22 Sets	3.832MHz	66dBi	81dBi	15dB	High
	Artillery	HQ Lt Rgt	3 Bat	22 Sets	4.497MHz	52dBi	81dBi	29dB	High
	Artillery	HQ Lt Rgt	2 Bat	22 Sets	3.396MHz	41dBi	81dBi	40dB	High
	Artillery	3 Bat	OC 3 Bat	22 Sets	4.530MHz	68dBi	81dBi	13dB	High

Table 2: Probability of Communications for Each Path

Broadly, it is apparent that the command links would have been less robust than those of the artillery. It is possible that if there had been equipment problems with the main command link from Division to Brigade, or if the antennas had been less efficient on the bridge end through poor location or damage, this link would have degraded leaving only the short hop command links and the artillery.

The conclusion overall from this work is that the communications should have worked as soon as the path lengths fell to around 6km between 22 Sets. If command links such as that from Div HQ to the bridge did not work then this failure was as a result of something other than transmission loss.

References

1 Electrical & Mechanical Engineering Regulations, F280, Wireless Set No. 22 Data Summary dated 15 March 1945.

2 Airborne Division Signals Instruction No.1 dated 30 May 1944

3 Element locations are from work by Maj. John Greenacre, Army Air Corps, 2003.

4 Needing operator intervention to keep on tune with location change. Tai, C.T. & Long, S. A., *Dipoles & Monopoles* in Radio Engineering Handbook, Ed. Johnson, R.C., pub Mc Graw Hill, 1993.

5 High Earth resistance means power and received signal are dumped to Earth rather than used.

6 The vertical radiation responses were produced using the NTIA/ITS software *ITSAnt*. *ITSAnt* is available at http://www.its.bldrdoc.gov/home/software/

7 From data received from DCSA, Royal School of Signals, Blandford Camp, Dorset.

8 See Recommendation ITU-R P.372-8: Radio Noise

9 Details on the functionality available from this radio network modelling tool can be found at www.atdi.co.uk.

10 ITU Rec. P.832-2: World Atlas of Ground Conductivities

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For further information on modelling methods visit www.atdi.co.uk.

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