Multilinking of Professional Analog Wireless Communication Networks.

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Abstract. The paper explains design of Professional Analog Wireless Communication System. The designing of basic analog wireless communication network, its components, their parameters and communication quality deciding factors are discussed. For expanding a wireless system, multilinking of wireless networks is essential. Major problem encountered during interconnections of such networks is time delay occurred due to propagation of electromagnetic waves through air. This paper suggests one method to eliminate the problem. It has been successfully implemented in one of the big cities in Maharashtra State.

Keywords: Professional Wireless network, Repeater, Linking, Delay Circuit.

1. Introduction
Professional wireless communication is becoming important in general or critical situations from ease of use and security point of view. The efficient communication between the security persons is more important than their weapons. Hence need of dense wireless communication is increasing day by day. More and more low power, portable devices are being used for communication for easy handling and mobility. As devices are becoming portable and low power, importance of strong wireless network is increasing. Many private companies are involved in designing portable and energy efficient wireless devices such as wireless sets and portables, network devices like repeaters for providing quality communication in critical or dense areas. This has proven its importance in many security critical operations for Police and Military Persons. There are many problems faced during formation of dense wireless network or linking of many wireless networks.

This paper focuses on the subject with following sequence.

1. Section 1 - Introduction: It provides short introduction of the subject.
2. Section 2 - Basic designing of Professional Analog Wireless Communication Network: It provides in depth process of designing professional analog wireless communication network. It covers in each designing aspect from technical point of view.
3. Section 3 - Need of Multilinking and Challenges: It gives detail description of need of multilinking of wireless communication and linking architecture. The section describes each process involved in linking and major problems encountered.
4. Section 4 – Rectification of Multilinking problem: It shows modification in system interface to eliminate the problem.
5. Section 5 – Observation and Conclusion: It summarizes the results of experiments and puts conclusion.
2. Basic Designing of Professional Analog Wireless Communication Network.
This section is divided into eight sub sections. It explains scope of wireless communication, need and technical design analysis.

2.1 Understanding scope of wireless communication : Before designing any wireless network it is essential to know scope of wireless communication. Wireless communication is used mostly in following five areas of applications.

2.1.1 Mobility - Most important parameter of wireless communication is mobility. It should be used where mobility has prime importance. It is mostly used in security, road patrolling, supervision of work, deep forest or remote areas, hospitals, industries, hills and mountains.

2.1.2 Rural areas - It is used in rural areas where landline communication is not economical or not feasible.

2.1.3 Prime need of voice communication – It is basically used where voice communication is most essential or it is equally important as good as life. For example search operations carried out by Police Army and other Forces.

2.1.4 Easy and fast installation.
2.1.5 Less infrastructure is required.

2.2 Need analysis
It is to carried out on following basis.

2.2.1 Voice communication method – It specifies whether simplex or semi duplex or full duplex communication is desired. In Professional Wireless Network Semi duplex method is used. In such network one to many communication is desired.

2.2.2 Type of call – One to one (selective call), one to many (group call), one to all (broadcast call) call has to be specified. It decides type of signalling in wireless devices.

2.2.3 Data communication scope – It decides short messages length, long file transfer, live chatting, internet connectivity etc. required in communication.

2.2.4 Number of locations – It confirms number of fixed and mobile locations.

2.2.5 Number of groups – It is necessary to confirm how many groups are required to be formed. There must be one control station for each group. That control station will monitor and control all activities in the group. Each group will be a single and totally independent network.

2.2.6 Interconnection of groups – It is necessary to decide whether it is essential to interconnect every group to every other group or all groups to one main group.

2.2.7 Budget – Financial budget available for such project.

2.3 Technical Analysis
It will first decide network requirements in terms of technical parameters. For this purpose it is necessary to

2.3.1 Decide Latitude, Longitude and Altitude of each fixed wireless station and control station.-It can be done using GPS meter. Example of GPS meter can be found in reference [1]

2.3.2 Define network borders – First define network borders on the map. For this purpose map can be prepared or help can be taken from Google map. Show all fixed wireless stations on the map. Fix the
range of movable stations (mobiles). This will define basic coverage and its intensity requirements.[2,3]

2.3.3 Decide approximate air distance between each static wireless station to every other wireless station. [4]

2.4 Frequency Analysis
It is the time to decide frequency to be used for wireless communication. Frequency used for wireless communication decides range of communication, type of communication method (voice, narrow band data, wide band data) and quality of communication. There is different zone of propagation for different range of frequencies [5]. For professional Radio, frequencies in the range of 2MHZ to 30 MHZ are used for long range communication, 66MHZ to 88 MHZ and 146 MHZ to 174 MHZ are used for medium range and 400 MHZ / 800 MHZ band is used for low range communication. Frequency can be used from ISM (Industry Scientific Medical) band, which do not require license but have low power of transmission and cannot be used for long range communication. On the other hand frequencies in the licensed band can use large transmitting power and can be used for long range communication. The frequencies are allocated by Indian Telecommunication Union all over the world. In India these frequencies are allocated by Wireless Planning and Coordination Wing which is Central Government Authority [8]. They allocate frequencies as per their NFAP 2011 (National Frequency Allocation Plan -2011) [9]. While submitting request proposal for frequency, several other information is required such as number of stations, location of each station, transmitting power, type of aerial used. The details can be found in reference [10]. It is also necessary to take license for the wireless equipment used.

2.5 Radio Frequency Network Analysis
It includes collection of information on following points.

2.5.1 Define number of groups and their corresponding control stations.-This activity is carried out by administration of the Project. They specify group and members of each group as per their requirement.

2.5.2 Decide location of repeater station - Once groups are formed, it is necessary to decide its member stations. If member station is static then it is necessary to decide its location in terms of latitude, longitude and altitude. If member station is movable then it is necessary to decide its range of mobility. Once all groups are decided with their corresponding geographical locations, it is required to find out whether communication is possible between them. This is done using some software. Examples of such software are as per reference [11]. If communication is not possible between every station to every other station, then suitable location is searched which provides connectivity to each and every member of the group. Such station is termed as Repeater. There can be one or more repeaters in a group. If more than one repeater is used it is necessary to connect them using another type of repeater called as Link Repeater. Each Repeater requires two frequencies for its half duplex operation. If there are more than one group, then interconnection of Repeaters in different groups is generally made in Star topology. In few exceptional cases they can be connected in Mesh topology.

2.5.3 Find out latitude, longitude and altitude of repeater station.

2.5.4 Number of frequency pairs needed. - Depending upon number of groups and repeaters, number of frequencies are decided and then those can be demanded for license.

2.5.5 Channel spacing between adjacent frequencies.- Once number of frequencies are decided, it is necessary to decide channel spacing between adjacent channels. The channel spacing is decided by type of modulation used. In analog communication, for Frequency/ Phase modulation channel spacing is defined as 25 KHZ for WBFM (Wide Band Frequency Modulation), 12.5 KHZ for NBFM (Narrow Band Frequency Modulation) [12]. Accordingly radio equipment need to be used and method of interconnecting of groups is decided.
2.5.6 Type of equipment to be used for outstation, portable devices and network devices - Depending on observations found under section 2.5, 2.3 for link formation between Repeater and each outstation and section 2.5 for choice of WB FM or NB FM, primary technical specifications for the Repeater Equipment and all Static and Mobile Equipment are decided. For finalization of Equipment Specification it is necessary to carry out link budget analysis as mentioned under section 2.6.

2.6 Link Budget analysis
As mentioned earlier under 2.5, using suitable software it is necessary to decide link feasibility between Repeater and every other station in the group. For deciding link feasibility basic transmitter parameters like RF power, frequency, Receiver parameters like sensitivity, selectivity, Antenna parameters like antenna gain, impedance, radiation pattern has to be adjusted for getting proper signal at receiver antenna in all seasons at all time. Link budget is used to decide specifications of transmitter, receiver, coaxial cable, antenna, antenna height ultimately height of mast.

Please refer [13,14,15] for detail information.

2.7 Network device requirements
Link budget analysis provides complete specification of all wireless devices used for outstation and repeater. Failure of repeater will cause failure of total wireless network. Hence sufficient redundancy is kept Repeater station. Repeater devices health monitoring system may be developed, which enable us to monitor the repeater status from control unit. This will help to attend the defects in the device earlier.

2.8 Installation phase
In installation phase, first all devices purchased are tested as per specifications. For this purpose various test equipments like RF Spectrum Analyzer [16], Through Line Wattmeter [17], RF Signal Generator [18], Frequency Counter [19], AF output Power Meter [20], Digital Storage Oscilloscope [21] are required. The sets, portables and repeaters are programmed as per frequency plan and RF power as per link budget power plan. The Repeater in a group is first installed and then all remaining wireless stations in that group are installed. If there are many groups, all other groups are installed in same procedure.

3 Need of Multilinking and Challenges
Multilinking is needed when there is a need of communication between different Groups. All the groups can communicate with a single group control station called as Master Station. With due permission of Master, it is possible to talk any person from any group to any other person in any other group. This process can be automated. Following are basic architectures for formation of group.

3.1 Wireless Network for a Single Group
The frequency plan of each group is prepared. Let say in Group 1, there is a Group repeater R1 and 20 outstations. Let us assume that the outstations are operating on Transmit Frequency of F1 MHZ and Receiver Frequency of F2 MHZ. Generally spacing between receiver frequency and transmitter frequency is 5 MHZ for VHF (146 MHZ to 176 MHZ) and UHF (450 MHZ to 490 MHZ) frequency range. The Repeater are operating on Receive Frequency of F1 MHZ and Transmit Frequency of F2 MHZ. The wireless systems are mostly used in broadcast call or group call. All the wireless sets at the outstation are operated in half duplex mode. The default operating mode for the wireless set is Receiver. For transmitting a speech, PTT (Press To Talk) switch on the Handset is pressed and then person talks.

Let a person in a group talks, by pressing his PTT. He transmits a frequency F1, which is received by the receiver at the repeater. After receiving a valid carrier, receiver produces audio output called as "RX AF" and a signal indicating valid carrier called as 'Auto PTT'. The audio output (RX AF) of the repeater receiver is connected to microphone input of the repeater transmitter. The Auto PTT signal is connected to PTT signal of the repeater transmitter. So when valid RF signal at frequency F1 is received at the repeater receiver, it is automatically retransmitted by the repeater transmitter at frequency F2 without changing speech or information signal. The Radio frequency signal at
Frequency F2 is received by all out stations (except originator) receivers. Basic theme of the repeater is shown in Figure 1. In this way communication processes in a Group.

Basic need of Repeater station is that it should be able to receive signal from each and every station in the group. After receiving the signal it retransmits it to another frequency. This signal should be strong enough, so that it should be receivable by all other stations in the group. Frequency Plan for a single group is shown in Table 1.

![Figure 1. Theme of Wireless Repeater](image)

| Group Number | Repeater Number | Out station frequency | Repeater frequency |
|--------------|-----------------|-----------------------|--------------------|
|              |                 | Transmitter F1        | Receiver F2        |
| 1            | 1               | F1                    | F2                 |

Professional radios are available with integrated receiver and transmitter unit called as Transceiver or TRX. In TRX, by default receiver is working and when Press to Talk (PTT) is pressed transmitter starts working and receiver stops working. Thus either transmitter or receiver is working at a time in TRX set.

3.2 Interconnection of two groups.
With the same theme discussed in section 3.1, we have formed two groups with frequency plan as shown in Table 2. Schematic of the network is shown in Figure 2.

| Group Number | Repeater Number | Out station frequency | Repeater frequency |
|--------------|-----------------|-----------------------|--------------------|
|              |                 | Transmitter F1        | Receiver F2        |
| 1            | 1               | F1                    | F2                 |
| 2            | 2               | F3                    | F4                 |

To implement this frequency plan, wireless sets are for Repeater-1, Repeater-2 and Link Repeater are programmed as shown in Table 3.

When user-A from Group-1 press PTT to talk, following events take place.
1. From user handset RF signal is transmitted at frequency F1 MHZ.
2. This signal is received in receiver RX-A of TRX-1 in repeater-1.
3. Receiver RX-A is interfaced directly to transmitter TX-B of TRX-2. TX-B transmits same signal at frequency F2 MHZ.
4. This signal is received in receiver RX-B of TRX-3 in link repeater.
5. Receiver RX-B is interfaced directly to transmitter TX-C of TRX-4. TX-C transmits same signal at frequency F3 MHZ.
6. This signal is received in receiver RX-C of TRX-5 in repeater-2.
7. Receiver RX-C is interfaced directly to transmitter TX-D of TRX-6. TX-D transmits same signal at frequency F4 MHZ.
8. Signal transmitted at F4 MHZ is received by all outstations of Group-2. In this example it is shown that User-B is receiving the signal.

Table 3. Frequency Plan for implementation for interlinking two groups.

| Set name | Receiver name | Receiver frequency in MHZ | Transmitter name | Transmitter frequency in MHZ | Used for |
|----------|---------------|---------------------------|------------------|-------------------------------|----------|
| TRX-1    | RX-A          | F1                        | TX-B             | F2                            | Repeater-1 |
| TRX-2    | RX-B          | F2                        | TX-A             | F1                            | Link Repeater |
| TRX-3    | RX-D          | F4                        | TX-C             | F3                            | Repeater-2 |
| TRX-5    | RX-C          | F3                        | TX-D             | F4                            |          |

When user-B from Group-2 press PTT to talk, following events take place.
1. From user handset RF signal is transmitted at frequency F3 MHZ.
2. This signal is received in receiver RX-C of TRX-5 in repeater-2.
3. Receiver RX-C is interfaced directly to transmitter TX-D of TRX-6. TX-D transmits same signal at frequency F4 MHZ.
4. This signal is received in receiver RX-D of TRX-4 in link repeater.
5. Receiver RX-D is interfaced directly to transmitter TX-A of TRX-3. TX-A transmits same signal at frequency F1 MHZ.
6. This signal is received in receiver RX-A of TRX-1 in repeater-1.
7. Receiver RX-A is interfaced directly to transmitter TX-B of TRX-2. TX-B transmits same signal at frequency F2 MHZ.
8. Signal transmitted at F2 MHZ is received by all outstations of Group-1. In this example it is shown that User-A is receiving the signal.

As this is half duplex communication only one way communication is possible at a time.

3.3 Interconnection of multiple groups
With the same technique it is possible to interconnect many groups to each other using star topology. In this system there will be one repeater for each group and one link repeater is required for connecting two repeaters. Thus it requires five repeaters and four link repeaters for connecting four groups as shown below in Figure 3.
Figure 2. Theme of Wireless Link Repeater for connecting two groups.

Figure 3. Theme of Wireless linking for connecting four groups.

The frequency plan for such system is shown in Table 3.
Table 4. Frequency Plan for four interlinking groups.

| Group Number | Repeater Number | Out station frequency | Repeater frequency |
|--------------|-----------------|-----------------------|-------------------|
|              |                 | Transmitter          | Receiver          |
| 1            | 1               | F1                    | F2                |
| 2            | 2               | F3                    | F4                |
| 3            | 3               | F5                    | F6                |
| 4            | 4               | F7                    | F8                |

By using same technique it is possible to connect many groups to a single group (Star topology), or interconnection of groups in mesh topology is possible. But as number of repeaters increases, delay in the signal path increases and there is annoying sound is produced called as tic tac sound. Once user releases PTT switch, all repeaters switch ON and OFF more than two to three times. The annoying sound and toggling of repeaters interrupts the communication and also degrades the audio quality. This makes it practically impossible to connect repeaters to each other.

4. Rectification of Multilinking problem

The main problem arises in multilinking of wireless repeaters is toggling problem. In following sections the reason of the problem and its rectification method is discussed.

4.1 Reason of “Toggling” Problem.

Let User-A is talking to User-B using Repeater-1, Link repeater and Repeater-2. The frequency plan will be as shown in Table 2. When user A presses PTT, the sequence of operation is given in section 3.2.1. The main cause of the annoying sound and toggling of repeaters occurs when user A (or any user) release PTT to end his speech. At the time of releasing PTT following actions takes place.

What happens when User-A Releases PTT to end its transmission

1. User-A releases PTT at time t=t0
2. Receiver-A of TRX1 gets the valid carrier up to time t=t1 after releasing PTT form user-A. The time delay t=t1-t0 depends upon the air distance between User-1 and Repeater-1. This shows that Repeater-1 transmitter do not turn OFF simultaneously with the transmitter of User-A. At time t=t1, Receiver-A of TRX-1 and transmitter-B of TRX-2 turns OFF completely.
3. Receiver-B of TRX3 gets the valid carrier up to time t=t2 after turning OFF of transmitter TX-B of TRX2. The time delay t=t2-t1 depends upon the air distance between Link repeater and Repeater-1. This shows that Link Repeater donot turn OFF simultaneously with repeater-1. At time t=t2 Receiver B of TRX-3 and Transmitter TX-C of TRX-4 are completely turn OFF. Turning OFF of transmitter of TRX-4 allows to receive in default receiver mode RX-D and turning OFF of Receiver RX-B of TRX-3 allows TX-A of TRX-3 to work if RX-D gets valid carrier.
4. Receiver-C of TRX5 gets the valid carrier up to time t=t3 after turning OFF of transmitter TX-C of TRX4. The time delay t=t3-t2 depends upon the air distance between Link repeater and Repeater-2. This shows that Repeater 2 do not turn OFF simultaneously with Link repeater. At time t=t3 Receiver C of TRX-5 and Transmitter TX-D of TRX-6 are completely turn OFF.
5. Thus during time t=t1-t2 transmission from TX-A of TRX-3can be received by RX-A of the TRX-1. And can be transmitted on frequency B using transmitter TX-B of TRX-2. This transmission from TX-B can be received from RX-B and toggling of Link repeater will take place.
6. Similar situation occurs between time period t2 and t3. In this time RX-D of TRX-4 and TX-A of TRX-3 is free. The transmission from TX-D of TRX-6 can be directly received by RX-D of TRX-4. The received signal from RX-D of TRX-4 is transmitted on frequency F1 using TRX-3. And again that signal is transmitted by TX-B and now toggling of Link repeater, Repeater-2 take place. Due to looping it may possible that Repeater-1, repeater-2 and link repeater toggles continuously.
4.2 Technique of removing the fault
To remove this fault two precautions must be taken while designing the circuit.

1. Turning ON of transmitter of Link Repeater should be delayed by time \( t = t_3 - t_2 \). This time depends on the air distance between Link Repeater and Repeater 1 or Repeater-2. So there is need to keep this delay time variable. By practical observations the time is set as 10 millisecond to 150 millisecond. It is observed for UHF range of frequencies in the band of 450 MHZ to 490 MHZ. Delay time varies a little with change in season and change from day to night.

2. Only one side of link is allowed for functioning.

4.3 Implementation details
At time \( t = t_2 \) Receiver-B of TRX3 stops functioning and its Transmitter-A is ready for transmission. As soon as Receiver-B stops functioning, trigger pulse is generated and applied to trigger input of Duel Mono Shot IC 74LS123. The Delay action starts. The delay \( t_d \) is made greater than \( (t_3 - t_2) \) time. This time delay prevents Transmitter-A of TRX-3 to become operative by pulling its PTT signal line high. Even though Receiver-D of TRX-4 gets carrier, it cannot turn ON the Transmitter-A of TRX3 because of OR ing of Auto PTT signal of Receiver-D of TRX-4 and Delayed Auto PTT signal of Receiver-B of TRX3. The Transmitter-A is inoperative till time \( t = t_4 \) and not allows tail of carrier from Transmitter-D of TRX-6 to reach to Receiver-A of TRX-1. Thus the temporarily inoperative Transmitter-A disables further chain of toggling and problem is nullified.

The delay time is adjustable from preset of 100 Kilo Ohm connected at pin 7 and 15 of IC 74LS123 independently. With the value of \( R = 100 \) Kilo ohm and \( C = 10 \) microfarad, delay is adjustable maximum to 330 m.sec.

The circuit is duplicated for Receiver-D of TRX4. This Link Special Interfaces TRX3 and TRX4 as shown in Fig. 4. For linking of multi groups, such interface has to be used at each Link Repeater shown in Fig. 3.

![Figure 4. Link Special Interface](image)

5. Observation and Conclusion
The wireless repeater linking system described above, is implemented in a big city in Maharashtra State in India. The results are as shown in Table 5. The modification in link repeater found very successful in removing the multilinking major issue. From the observations it is concluded that for VHF or UHF frequency range, a special link interface circuit as shown in Figure 4 is required to simulate the delay which neutralizes the delay encountered in propagation of electromagnetic waves through air.
Table 5. Observations and Results

| Sr. No. | Frequency range | Air distance between Link Repeater and Main Repeater | Approx. signal strength at receiver | Delay practically experienced |
|---------|-----------------|-----------------------------------------------------|-----------------------------------|-------------------------------|
| 1       | 450MHZ to 490 MHZ | 2 KM to 5 KM                                      | -100dbm                           | 10msec to 150 msec.           |
| 2       | 146 MHZ to 174 MHZ | 20 KM to 30 KM                                    | -100dbm                           | 50msec to 250 msec.            |

6. Acknowledgement
To build a wireless network and its multilinking is a field critical job. The physical distance between two networks is large. It is essential to know status of each and every network for the rectification of the toggling problem. My officers and staff provide me a great help by providing field status of wireless networks at the time of fault situations. This provides a great data for me to rectify the problem and to come to conclusion. I sincerely thanks to all my officers and staff in Maharashtra State Police Wireless Department for extending me valuable help from time to time.

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