

Reducing Intermittent Call Reception Problems Due to Multipath Signal in GSM Networks using Intelligent Frequency Hopping Technique

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Abstract- Intermittent call reception in GSM network is as a result of unsteady signal caused by multiple versions of the transmitted signal arriving at a point. To reduce this unsteady reception an intelligent frequency hopping technique was used. To achieve that, a multipath reception model was simulated first to determine the number of multipath signals arriving at the reception point. Then the operating frequency was varied until a good network signal was received. If further transmissions was done using that frequency, steady signal reception will be achieved at that point and thereby reducing if not eliminating completely intermittent call reception at that location.

Keyword: Intermittent call reception, multipath signal, frequency hopping

1.0 INTRODUCTION

Mobile Communication has become a necessity for many people throughout the world. The ability to keep in touch with family, friends, business associates, and access internet services anywhere and at any time are only a few of the reasons for the increasing importance of Mobile Communication [1]. It has also not only provided users with a sense of security but in the event of emergency, having a mobile phone for example can allow help to reach one quickly and could possibly save lives. Modern mobile phones are capable of, sending and receiving photos and files, instantly send data to the home or office, check for important e-mail, use mobile phone as a PDA or calendar, and store photos which can be easily transferred to a PC or laptop computer [2]. Some mobile phones are also equipped with GPS technology, allowing for use in many locations around the world and allowing the mobile phone or system to be found or the user located in the event of loss, emergency or theft (tracking systems).

However, in a world where mobility is becoming a top priority for professionals and consumers alike, it is surprising that stable network reception, call quality and voice quality have continued to deteriorate most unfortunately even with increase in subscription. Problems ranging from frequent drop calls, bad quality voice calls, blocked calls, absent of network at some locations in the network coverage,

inability to get connected even after several trials are common. Long call set up time, intermittent call receptions and delays in messaging are some of the other problems. According to the February 18, 2011 report from Power J.D & Associate, call quality and unstable network reception problems have increased considerably with wireless calls in 2011 [3]. This phenomenon is worst experienced in the developing countries.

The 2012 semi annual study, [3] measured wireless call quality based on seven problem areas that impact on overall carrier performance: intermittent/dropped calls; static/interference; failed call connection on the first try; voice distortion; echoes; no immediate voicemail notification; and no immediate text message notification. The report found that out of 100 calls placed, 10 experienced problems of call interruptions alone.

In fact intermittent reception of ongoing calls and drop calls has of late become an endemic problem in Nigeria [4]. Intermittent call reception is a situation whereby a subscriber will be on a call and suddenly he/she will not be hearing the other person again, but after a short moment the call will be restored only to fail and probably restore again. If the condition persists the call may eventually drop. In some other instances one may be on call while driving or may be in a moving vehicle suddenly the call may cease only to come again after a short time.

These unpleasant and frequent re-occurring situations often lead to lots of frustration and disenchantment with the result that mobile network users do not enjoy the value of what they paid for. One funny thing about these conditions are that at a location where one is not receiving unsteady network coverage with say network operator A but with a phone with network operator SIM B will be receiving full and steady network coverage. This is why many Nigerians carry about more than two phones so that if one network fails at the location where he/she is, the other one may likely be receiving.

With the recent advancements in technology this problem which is caused by fluctuations in received network signal level due to fading should not continue and that is the motivation for this work. The work is based on improving the received signal level at the locations where received signal level is sometimes not sufficient to carry calls either in receive or transmit direction.

2.0 Theory of the research

Intermittent call receptions is as a result of frequent changes in the level of the received signal from the base transceiver at the point of reception - a phenomenon known in electronic communication as fading. In radio communication the two main factors that cause signal fading are [5]:

Path Loss, also known as large scale fading is largely due to the distance between the transmitter and the receiver.

Multipath Reception (small scale fading) caused by the propagated signal arriving at the receiving point in several of its versions which can combine constructively or destructively at any point in the coverage area.

Path loss obeys the Inverse square law which states that the received power (P_r) per unit area from a point source varies inversely according to the square of the distance (d) from the point source ($P_r = P_t/d^2$). In other words, the propagated signal strength (P_t) reduces as the signal moves away from the transmitter [2].

For multipath reception, studies have shown that it is as a result of four major issues caused by

physical factors in a radio communication channel, and which most times affect mobile signal strength as it travels from the base station to the mobile receiving unit and vice versa resulting in intermittent call receptions and failures [6]. These factors include: reflection, diffraction, obstruction and scattering of the propagated signal as result of such structures like buildings, trees and other obstacles on the path of the propagated signal (see figure 1.1). There are other factors like rainfall, wind, call traffic etc. The result is that several versions of the transmitted signal arrives a receiving spot and the combination of this arriving signal will form the received signal level at the point. If the combination is more constructive a good signal is therefore received and hence a good network, but if the reception is more destructive we have a degraded reception which may result in occasional or total absence of network.

Since the presence of the obstacles in free space cannot be controlled or eliminated, one therefore has to devise a means of overcoming its effects in order to maintain a good quality communication that will avoid intermittent receptions. This work is therefore on reducing the adverse effect of multipath reception of propagated signal in space [7].

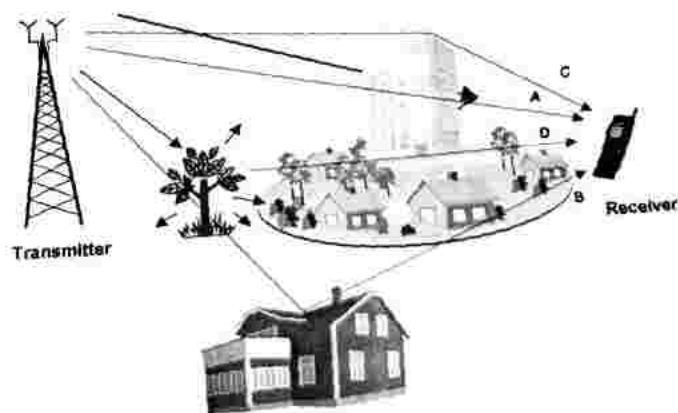


Fig 1: A typical Multipath Environment

A: Free space reception C: Received diffracted signal E: Blocked signal
B: Received reflected signal D: Received scattered signal

In signal reflection, the reflecting object is large compared to the signal wavelength. For a signal

to be scattered, the scattering object is small compare to the signal wavelength or its surface is irregular.

Multipath Reception Models

As earlier stated, multipath signals result from obstacles on the path of the signal propagated between the transmitter and the receiver. The same signal arrives at the receiving node through various propagation paths created by the obstacles between the node and the transmitter [6]. The arriving signals have different amplitude and phase differences among one another so that the overall resulting signal varies from slightly more strengthened (signal reinforcement) to considerably less strengthened (signal cancellation) compared to a single signal [8].

2.1: Signal Reception at different Positions of Scatterers and Receiving Units

There are different types of models to deal with different situations as follows:

Models for multipath signal

- when both the mobile unit and some of the nearby scatterers are all stationary.
- when both the mobile unit and some of the nearby scatterers are all moving.
- when the mobile unit is standing and some of the nearby scatterers are moving

2.1.1 Reception when both the Mobile Unit and nearby Scatterers are all Stationary

This is a static multipath situation: the various signal paths resulting from the numerous scatterers, reflectors, deflectors, etc, reaching the mobile unit can be individually identified in theory as modelled in Figure 2. Assuming we have k signal paths, the received signal reaching the stationary mobile unit, can be expressed by the following equation [6]

$$s(t) = \sum_{i=1}^k a_i s_0(t - \tau_i) \quad (1)$$

$$s_0(t) = a_0 \exp[j(\varphi_0 t + \varphi_0)] \quad (2)$$

where,

$s(t)$: received signal

a_i : i^{th} transmission attenuation factor

$s_0(t)$: the transmitted signal

t : time

τ_i : i^{th} signal path (time delay)

a_0 : amplitude of the transmitted signal

ω_0 : angular frequency of the transmitted signal

φ_0 : phase of the transmitted signal

$\omega_0 = 2\pi f_0$ where f_0 is the frequency of transmitted signal.

For the i^{th} path, the total propagation time can be expressed by the equation

$$\tau_i = \bar{\tau} + \Delta\tau_i \quad (3)$$

$$\bar{\tau} = \frac{1}{k} \sum_{i=1}^k \tau_i \quad (\bar{\tau} \text{ is mean value of } \tau) \quad (4)$$

From equation (1) a_i is the i^{th} path transmission – attenuation factor, which can be a complex value, substituting the value of $s_0(t)$ in equation (1), then

$$s(t) = \chi(t - \bar{\tau}) \exp[j2\pi f_0(t - \bar{\tau}) + j\varphi_0] \quad (5)$$

The envelope $\chi(t)$ of the received signal $s(t)$ is expressed as

$$\chi(t) = a_0 \left[\sum_{i=1}^k a_i \exp(-j2\pi f_0 \Delta\tau_i) \right] \quad (6)$$

From the received envelope (eq. 6) a_0 is constant; the rest of that equation represents the multipath phenomenon. Since this equation is independent of time t , then $\chi(t)$ is also constant with respect to time. The received signal envelopes of $s(t)$ therefore remain unchanged, so long as the mobile unit and the nearby scatterers are all standing.

Examples of moving scatterers are passing cars and trucks, aero plane, foliage during windy condition etc. In this case, time delay, τ_i and the attenuation constants a_i will be uniquely different at any instant of time along the i^{th} path

Then received signal $s(t)$ in equation (5) will now change to

$$s(t) = \chi(t) \exp(j\varphi_0) \exp(j2\pi f_0 t) \quad (7)$$

Given that

$$x(t) \sum_{i=1}^k a_i a_i(t) \exp(-j2\pi f_o(t)) \quad (8)$$

Unlike the previous case the amplitude and phase of the arriving multipath signal are changing with time. Hence $\chi(t)$ which contains

the transmitted message will be changing at any instant of time.

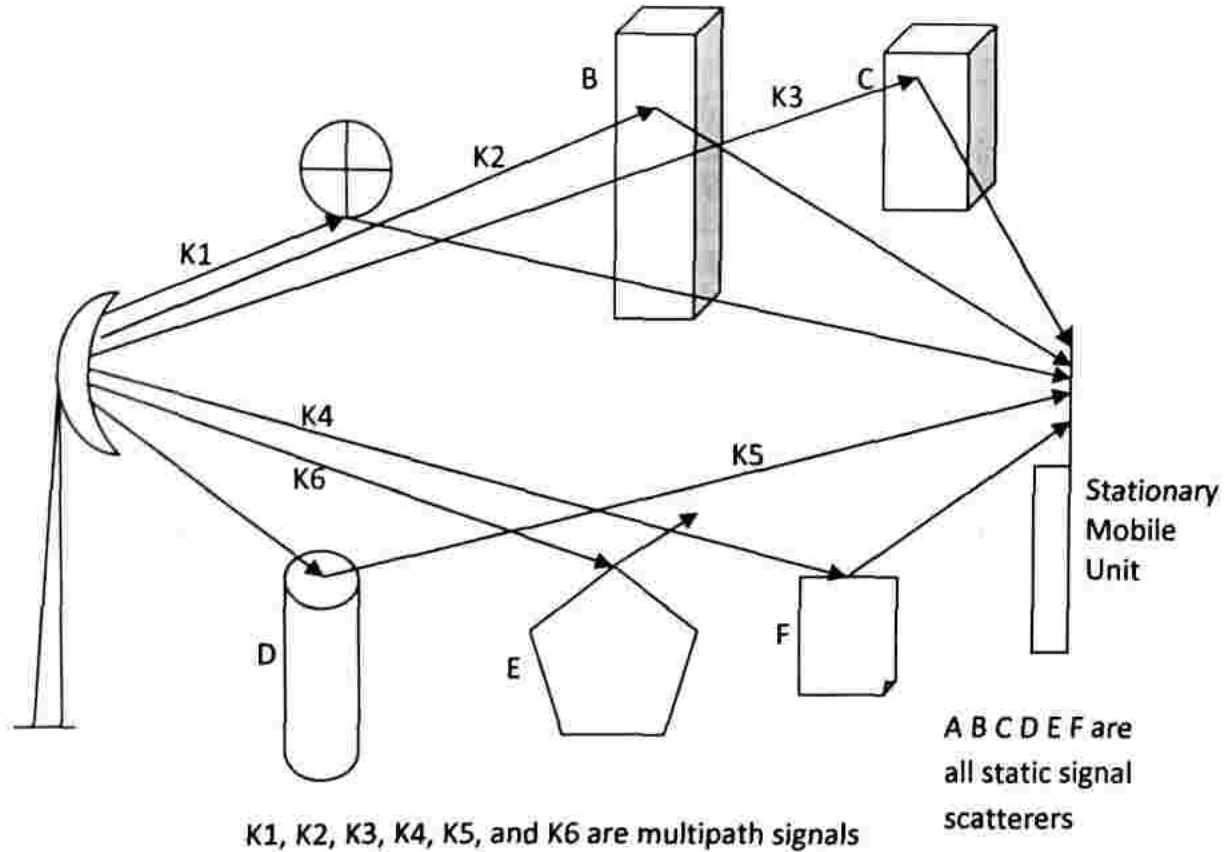


Figure 2: Static multipath situation when both mobile unit and scatterers are all stationary

2.1.2: Reception when both the mobile unit and the nearby scatterers are all moving.

In this case the resultant received signal is the sum of all scattered waves from different angles θ_i , depending upon the momentary attitude of the various scatterers and whether or not the direct signal transmission path is blocked. This is expressed as follows:

$$s(t) = \sum a_i a_i \exp [j(\omega_0 t + \phi_0 - \beta v t \cos \theta_i + \phi_i)] \\ = A_i \exp (j\psi_i) \exp [j(\omega_0 t + \phi_0)] \quad (9)$$

But A_i is given as

$$A_i = [(a_0 \sum a_i \cos \psi_i)^2 + (a_0 \sum a_i \sin \psi_i)^2]^{1/2} \quad (10)$$

$$\psi_i = \tan^{-1} \frac{\sum a_i \sin \psi_i}{\sum a_i \cos \psi_i} \quad (11)$$

And $\psi_i = \phi_i - \beta v t \cos \theta_i$

2.2: Intermittent Call Receptions

In intermittent call receptions, mobile users experience momentary call failures of an ongoing call which in many cases may not terminate the call unless it is prolonged. This is different from call drops where the call is terminated completely meaning that the call has to be initiated again for the conversation to continue. Intermittent call reception is a problem of fading where the signal level keeps changing because of the environment. The rate of the signal changes can be determined using the model of this work.

Different types of signal booster systems meant to boost received signal have been used to reduce problems of intermittent call receptions,

dropped calls and blank network reception points (dead zones). But they have not been very effective.

2.3: Call Drops

Call Drops

Call drop is the common term for a wireless mobile phone call that is terminated unexpectedly as a result of technical reasons, including presence in a dead zone (deep fade zone). One reason for a dropped call is when the mobile phone moves out of range of a wireless network. An active call cannot usually be maintained across a different company's network (as calls cannot be re-routed over the traditional phone network while in progress), resulting in the termination of the call once a signal cannot be maintained between the phone and the original network [3].

One other common reason is when a mobile receiving unit is taken into an area where wireless communication is unavailable or is interrupted due to frequent signal level changes, interfered with, or jammed. From the network's perspective, this is the same as the mobile moving out of its network coverage area.

Occasionally calls are dropped upon handoff between cells within the same provider's network. This may be due to an imbalance of traffic between the two networks areas of coverage. If the new cell site is at capacity, it cannot accept the additional traffic of the call trying to "hand in." It may also be due to the network configuration not being set up properly, such that one cell site is not "aware" of the cell to which the phone is trying to handoff. If the phone cannot find an alternative cell that can take over the call, the call is lost and will drop.

Co-channel and Adjacent channel interference can also be responsible for dropped calls in a wireless network [2]. Neighbor cells with the same frequencies interfere with each other, deteriorating the quality of service and producing dropped calls. Transmission problems are also a common cause of dropped calls. Another problem may be a faulty transceiver (XCVR) inside the base station.

Calls can also be dropped if a mobile phone at the other end of the call loses battery power and stops transmitting abruptly. Call drop rate (P) when a mobile unit is located in handoffs region for example can be determined by the model below

$$P = 1 - X^{n+k} \quad (12)$$

$$X = (1 - \delta) (1 - \mu) (1 - \tau\theta) (1 - \beta)^2 \quad (13)$$

k = an assumed no of regular handoffs while the mobile unit

is passing through k+1 cells

δ = the probability that the signal is below a specified reception

threshold (in a noise-limited system) sometimes due to fading.

μ = the probability that the signal is below a specified co channel

interference level (in an interference-limited system)

τ = the probability that no traffic channel is available upon handoff attempt when moving into a new cell.

θ = the probability that the cell will return to the original cell

β = the probability of blocking circuits between BSC and MSC

during handoff

Methods adopted by various researchers for reducing the effect of frequent changes the level of received radio signal includes

Spatial diversity, Signal Polarization, Time diversity, Frequency hopping

2.4: Frequency Hopping Modes

Frequency hopping is the technique of improving the signal to noise ratio in a link by adding frequency diversity. In other words frequency hopping means that multiple frequencies are used for the transmission of speech or data in a single connection. Each burst is transmitted on a fixed frequency, but the frequency is changed between bursts [9]. A burst can easily be lost when the mobile happens to be located in a fading dip for that particular frequency, or if it is subjected to interference. The next burst, if on a different frequency, has a good chance to come through. The coding and interleaving scheme in GSM is constructed so

In cyclic hopping mode the same hopping sequence will be used periodically. The transmitter "hops" between available frequencies according to a specified algorithm in synchronization with the receiver, which remains tuned to the same centre frequency as the transmitter. A short burst of data is transmitted on a narrowband. Then, the transmitter tunes to another frequency and transmits again. The receiver thus is capable of hopping its frequency over a given bandwidth several times a second, transmitting on one

frequency for a certain period of time, then hopping to another frequency and transmitting again. *Frequency hopping* requires a much wider bandwidth than is needed to transmit the same information using only one carrier frequency.

In random hopping mode a pseudo random sequence will be used in order to achieve uncorrelated hopping sequences as compared with the cyclic mode where the same hopping sequence will be used periodically.



It is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is utilized as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme. A spread-spectrum transmission offers three main advantages over a fixed-frequency transmission:

- (b) Spread-spectrum signals are difficult to intercept. An FHSS signal simply appears as an increase in the background noise to a narrowband receiver. An eavesdropper would only be able to intercept the transmission if the pseudorandom sequence was known.
- (c) Spread-spectrum transmissions can share a frequency band with many types of conventional transmissions with minimal interference. The spread-spectrum signals add minimal noise to the narrow-frequency communications, and vice versa. As a result, bandwidth can be utilized more efficiently.

2.8: Dynamic Frequency Hopping Mode

In this method, the transmit and receive carrier frequencies of the network are dynamically assigned based on current interference and traffic environments to avoid interference. This prevents collisions between frequencies due to the fact that all the channels of a cell, even when they use the 'random' frequency hopping, do it in such a way that they never use the same frequency at the same time. The method gives both the frequency diversity (protection against the fading on one frequency, better effect with cyclic hopping) and the interfere diversity (protection against user mobiles using the same frequency, better effect with random hopping [12]).

Dynamic frequency hopping imposes less stringent measurement requirements on terminals (wireless mobile devices) because many measurement requirements are replaced by generating estimates based on measurement data received from other base stations within a base station neighbourhood. A base station neighbourhood of a first base station is a group of second base stations that may be affected by first links serviced by the first base station. The base station neighbourhood may be defined by a link neighbourhood. A link neighbourhood of a link includes all other links whose interference to the link exceeds an interference threshold. Thus, any of the first links that is included in link neighbourhoods of second links serviced by the second base stations may interfere with the second links. Therefore, the second base stations are included in the base station neighbourhood of the first base station.

The dynamic frequency hopping system may continuously verify that the frequency hopping patterns assigned to the links of the system optimizes an estimated system performance. Each currently assigned frequency hopping pattern is compared against all other possible frequency hopping patterns that may be assigned to a particular link. A possible frequency hopping pattern that corresponds to a maximum possible estimated system performance is compared against a current estimated system performance corresponding to the current

frequency hopping pattern. If the current estimated system performance is less than the maximum possible estimated system performance, then the frequency hopping pattern of the particular link is changed to the possible frequency hopping pattern to improve system performance [13].

When a request for a link is received by the dynamic frequency hopping system, a similar process as above is performed where the request is granted allocation of system resources and assigned a frequency hopping pattern if the total estimated system performance exceeds a performance threshold. If the performance threshold is not exceeded, then the request for a link may be either delayed or denied. In this way, the frequency hopping patterns of all the links of the system may be assigned so that an optimum system performance may be obtained.

2.9: Frequency Hopping Implementation Techniques

Frequency hopping in the base stations can be implemented in either of two ways: Baseband Hopping (BBH) and Synthesizer frequency hopping (or Radio Frequency Hopping RFH). Their operation differs in the way they establish the Base to Mobile Station link (downlink), however there is no difference at all between Mobile Station to Base Station link in both types of hopping.

In Baseband Frequency Hopping (BBH), each transmitter (TRX) is transmitting on one fixed frequency. Hopping is performed by switching the mobiles from burst to burst to different carrier units (CU) of the BTR. Within the BTR the baseband part (FU) is separated from the RF-part (CU). Thus SFH is realized by switching the FU to the respective CU via an internal switch. The amount of hopping frequencies $N(\text{hop})$ is determined by the number of TRXs $N(\text{TRX})$: $N(\text{hop}) \leq N(\text{TRX})$. Note, that a BTR equipped with only one TRX cannot perform baseband hopping.

For Synthesizer Frequency Hopping (SFH) the transceiver (TRX) does not get fixed frequency assignments; they may change their frequency from time slot to time slot according to a predefined hopping sequence. In such a system

the number of applicable hopping frequencies may be larger than the number of equipped TRXs: $N(\text{hop}) \geq N(\text{TRX})$.

Since no hopping on the BCCH frequency is allowed, synthesizer frequency hopping must

not be performed on the BCCH TRX. Figure 4 shows both hopping modes. TRX1 represents the BCCH frequency, where the BCCH information is transmitted on timeslot 0. Note that mobiles being connected to TRX1 can only hop in baseband hopping mode.

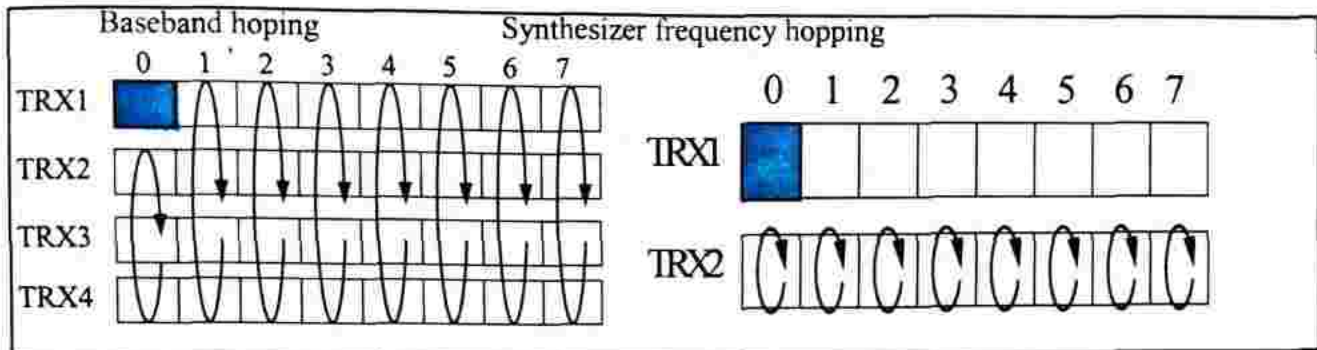


Fig 4: Baseband and Synthesizer Frequency Hopping

A drawback of the synthesizer hopping configuration is that the BTR cannot be equipped with remote tuneable combiners (RTC), since the tuneable filters cannot change their frequency on a timeslot basis. Therefore a wideband combiner (WBC) has to be used for the connection between transmitter and antenna, resulting in 3.45 dB additional downlink loss. One WBC combines 2 TRX with an insertion loss of 5.05 dB (including 1.6 dB duplexer losses), one RTC usually combines maximum of 4 TRX with an insertion loss of 3.2 dB. In a baseband hopping system the transmitter is tuned to a fixed frequency, thus RTCs can be used in such a configuration.

Frequency Hopping Operations

Frequency hopping is the process of transmitting radio signal by changing from one frequency to another as the transmission goes from one time slot to another in the transmission frame. Cellular networks use frequency hopping to mitigate fading and thus improve the transmission quality [14].

The overall bandwidth required for frequency hopping is much wider than that required to transmit the same information using only one carrier frequency. However, because transmission occurs only on a small portion of this bandwidth at any given time, the effective

interference bandwidth is really the same. Whilst providing no extra protection against wideband thermal noise, the frequency-hopping approach does reduce the degradation caused by narrowband interferers.

One of the challenges of frequency-hopping systems is to synchronize the transmitter and receiver. One approach is to have a guarantee that the transmitter will use all the channels in a fixed period of time. The receiver can then find the transmitter by picking a random channel and listening for valid data on that channel. The transmitter's data is identified by a special sequence of data that is unlikely to occur over the segment of data for this channel and the segment can have a checksum for integrity and further identification. The transmitter and receiver can use fixed tables of channel sequences so that once synchronized they can maintain communication by following the table. On each channel segment, the transmitter can send its current location in the table. A lot of other approaches such as the one used for the realization of this work has also been developed.

Slow and Fast Frequency Hopping

Frequency hopping consists in changing the frequency used by a channel at regular intervals.

One distinguishes fast frequency hopping (FFH), where the frequency changes quicker than the modulation rate, from slow frequency hopping (SFH), which is the most commonly used in cellular systems. GSM for example uses a TDMA system with 8 timeslots. In slow frequency hopping each mobile transmits or receives on a fixed frequency during one timeslot and hops to another frequency before the next timeslot will be transmitted or received, resulting in 217 hops per second for the mobile station [2]. This technique can be applied on all traffic and signalling channels, except the BCCH channel, which must transmit on a fixed frequency, to make correct RXLEV measurements for the neighbor cell mobiles possible. Moreover, the BCCH channel has to transmit full power on all timeslots. Thus SFH, PC and DTX are not allowed on the BCCH carrier.

Frequency Hopping Parameters

GSM defines the following set of parameters [14]: Mobile Allocation (MA): Set of

frequencies the mobile is allowed to hop over. Maximum of 63 frequencies can be defined in the MA list.

Hopping Sequence Number (HSN): Determines the hopping order used in the cell. It is possible to assign 64 different HSNs. Setting HSN = 0 provides cyclic hopping sequence and HSN = 1 to 63 provide various pseudorandom hopping sequences.

Mobile Allocation Index Offset (MAIO): Determines inside the hopping sequence, which frequency the mobile starts to transmit on. The value of MAIO ranges between 0 to (N-1) where N is the number of frequencies defined in the MA list. MAIO is set on per carrier basis.

Frequency Hopping Indicator (FHI): Defines a hopping system, made up by an associated set of frequencies (MA) to hop over and sequence of hopping (HSN). The value of FHI varies between 0 to 3. It is possible to define all 4 FHIs in a single cell.

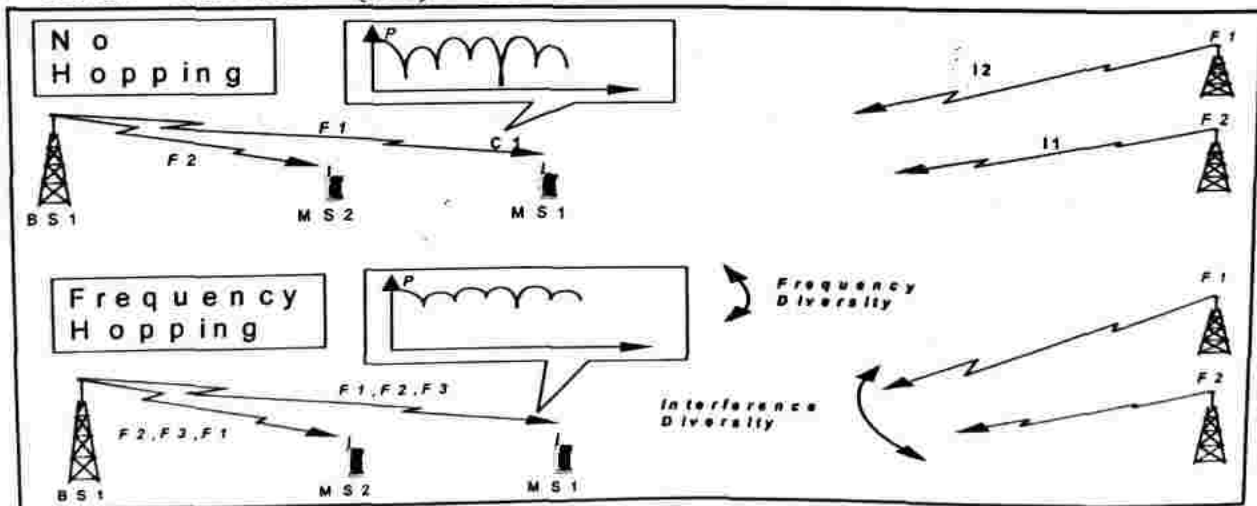


Fig 5: Effect of Frequency and Interferer Diversity

3.0 METHODOLOGY

Intelligent frequency hopping is the method used in the realization of this research which is the reduction of intermittent call reception problems being encountered in GSM networks. Frequency hopping has been found to be good method adopted and proved through research to be an

effective way of mitigating the effect of fading in cellular environments. Previous effort at reducing fading using this method employed various models of frequency hopping as already explained. The problem with those models being that many of the frequencies used in the hopping operations never played any role in improving signal reception so that those frequencies which ought to be used for other purposes were wasted and transmission bandwidth increased in the

process with its attendant problems. The realization of this work was therefore based on an intelligent application of frequency hopping to reduce the effect of fading employed a different approach.

In this technique, any mobile equipment which finds itself at the location of unstable or blank network reception spot in a cell coverage area (which causes intermittent call receptions) will first monitor the environment of the location, evaluate the data collected and decide the right frequency to be transmitted to enable the point receive a good network signal. The frequency obtained from the result of the evaluation (of the environment) will be communicated to the intelligent frequency hopping transmitter which will then cause the next transmission process to be transmitted at that frequency. This way the unstable and blank network will no longer be a problem to the spot and that frequency will likely clear other bad spots in the cell site since they are in the same environment.

Simulation works on a multipath model were employed to obtain the right frequency at any problem spot that when used in the next transmission will improve the signal level at that spot for good network operations.

Characterization of a Fading Channel

Since previous research has proved that frequency hopping can improve signal reception at a fading spot, it was therefore very important to characterize the fading environment and obtain a research model for this work. The study environment for this work is multipath reception when the mobile unit is steady and some of the signal scatterers are moving.

Analysis of the Properties of a Carrier Signal

To properly understand how multiple paths signal affects received signals, the properties of the carrier signal transmitted from the base transceiver were first examined and analyzed. A transmitted signal can be expressed as follows [6]:

$$S_0(t) = a_0 \exp [j(\omega_0 t + \phi_0)] \quad (14)$$

The power within the transmitted carrier frequency is the real part of $S_0(t)$, this is expressed as $\text{Re} [S_0(t)]$. However, this work is

only interested in the received baseband signal, which is derived from the amplitude and phase of the received RF signal.

As earlier stated, there are three conditions apart from factors, which could affect received signal at any spot in GSM environment. In this work, signal reception when the mobile unit is stationary and some of the scatterers are moving was considered and adopted as the research focus. In this case, time delay τ_i , and the attenuation constants, a_i of every multipath signal will be uniquely different at any instant of time along the multipath, for example the i^{th} path.

Under the above condition the received signal $s(t)$ will be

$$s(t) = \chi(t) \exp (j\phi_0) \exp (j2\pi f_0 t) \quad (15)$$

Given that

$$x(t) = \sum_{i=1}^k a_i a_1(t) \exp [-j2\pi f_0 \tau_i(t)] \quad (16)$$

$s(t)$ = received signal

a_i = attenuation constant of the received i^{th} multipath signal

f_0 = operational frequency

τ_i = time delay by the i^{th} multipath received signal

$\chi(t)$ = received signal envelope which contained transmitted message

k = No. of arriving multipath signals

$$N = \sum_{i=1}^k a_i(t) \cos[2\pi f_0 \tau_i(t)] \quad (17)$$

And

$$S = \sum_{i=1}^k a_i(t) \sin[2\pi f_0 \tau_i(t)] \quad (18)$$

Then

$$\chi(t) = a_0 [R - jS] = A(t) \exp[-j\psi(t)] \quad (19)$$

The amplitude and phase of $\chi(t)$ are expressed as time-dependent variables meaning that the received signal is time dependent.

$$A(t) = a_0 \sqrt{N^2 - S^2} \quad (20)$$

$$\Psi(t) = \tan^{-1} \frac{S}{N} \quad (21)$$

The envelope of the received signal (eqn16) will be the research model for this work since it contains the variables that causes signal unsteadiness in the received signal.

Observations in the research model

A critical look at the research model shows that the received signal when the receiving equipment is stationary and some of the scatterers are moving, is time dependent since the two variables (frequency and time delay) in the model are time dependent. And since we cannot do anything with the time delay variable because it depends entirely on the environment which of course we cannot control, the only variable in the model that can be manipulated to achieve a better reception is therefore the frequency component.

4.0 MATLAB Simulations

From the research model, received signal $\chi(t)$ depends on two variables:- time delay(τ_i) caused by the environment and the frequency of the propagated signal (f_0). These are the parameters that can be manipulated to improve the received signal level at any location. But it is not possible to control the number of multipath signals or even their time delay, as they depend on the environment; one is therefore left with only the transmitting frequency for the improvement of received signal at any point.

Referring to equation (16),

$s(t)$ is the received signal

$\chi(t)$ is the received signal envelope

a_0 is the free space attenuation constant

a_i is the attenuation constant of the i th multipath signal (in flat fading which we are considering the attenuation constant is equal for all arriving multipath signal)

f_0 is the frequency of the transmitted signal,

τ_i the time delay for the received i th multipath signal (τ defines the number of multipath signals that arrive a location).

In working with model, the following assumptions were made

$\chi(t) = P(r) = -93\text{dBm}$; received signal ($P(r)$) at a bad spot. This signal level cannot sustain network transmission or reception in a cellular network (MTN)

$a_0 = 10 \log P(t)/P_r$; free space attenuation constant ($P(t)$ is propagated signal power)

$a_i = 100\text{pw}$; attenuation constant of the arriving multipath signal. (From research, attenuation constant for all the multipath signal is equal in flat fading ()).

$f_0 = 960\text{MHz}$; operating frequency of the network of study

5.0 PROCEDURE

Using the research model equation (16), and the designed operational flowchart as given in figure 6 we define and determine the parameters of the project model which is used to develop a simulation model for the implementation of the signal improvement process in this research

With the simulation flow chart, the process is explained as follows.

First Simulation

Since all other parameters are known, only τ – the number of the arriving multipath signals that sum up to the received signal strength of -93dBm is yet to be determined. The first simulation result shows that the number of multipath signals (τ) that made up the -93dB received signal is 81 in number as given in as given in table 1 (multipath signal versus received signal level).

Table 1: Number of arriving multipath signal (τ) and Received Signal ($\chi(t)$)

Number of arriving multipath signal (τ)	Received Signal $\chi(t)$ (dBm)	Number of arriving multipath signal (τ)	Received Signal $\chi(t)$ (dBm)	Number of arriving multipath signal (τ)	Received Signal $\chi(t)$ (dBm)	Number of arriving multipath signal (τ)	Received Signal $\chi(t)$ (dBm)
1	-1.16	23	-26.65	45	-52.14	67	-77.62
2	-2.32	24	-27.81	46	-53.29	68	-78.78
3	-3.48	25	-28.96	47	-54.45	69	-79.94
4	-4.63	26	-30.12	48	-55.61	70	-81.10
5	-5.79	27	-31.28	49	-56.77	71	-82.26
6	-6.95	28	-32.44	50	-57.93	72	-83.42
7	-8.11	29	-33.60	51	-59.09	73	-84.58
8	-9.27	30	-34.76	52	-60.25	74	-85.73
9	-10.43	31	-35.92	53	-61.40	75	-86.89
10	-11.59	32	-37.07	54	-62.56	76	-88.05
11	-12.74	33	-38.23	55	-63.72	77	-89.21
12	-13.90	34	-39.39	56	-64.88	78	-90.37
13	-15.06	35	-40.55	57	-66.04	79	-91.53
14	-16.22	36	-41.71	58	-67.20	80	-92.69
15	-17.38	37	-42.87	59	-68.36	81	-93.84
16	-18.54	38	-44.03	60	-69.51	82	-95.00
17	-19.70	39	-45.18	61	-70.67	83	-96.16
18	-20.85	40	-46.34	62	-71.83	84	-97.32
19	-22.01	41	-47.50	63	-72.99	85	-98.48
20	-23.17	42	-48.66	64	-74.15	86	-99.64
21	-24.33	43	-49.82	65	-75.31	87	-100.80
22	-25.49	44	-50.98	66	-76.47	88	-101.95

Second Simulations

Now having determined the number of multipath signals that resulted in the received signal level

of -93dBm to be 81, then using the simulation model the transmitting frequency was varied from 935MHz to 965MHz and the result obtained is given in table 2.

Table 2: Operating Carrier Frequencies vs Received Signal Strength for each Frequency

Frequency (F) (MHz)	Received Signal $\chi(t)$ (dBm)	Frequency (F) (MHz)	Received Signal $\chi(t)$ (dBm)	Frequency (F) (MHz)	Received Signal $\chi(t)$ (dBm)
935	-1.16	946	-25.49	957	-50.98
936	-3.48	947	-27.81	958	-53.29
937	-4.63	948	-30.12	959	-55.61
938	-6.95	949	-32.44	960	-57.93
939	-9.27	950	-34.76	961	-60.25
940	-11.59	951	-37.07	962	-62.56
941	-13.90	952	-39.39	963	-64.88
942	-16.22	953	-41.71	964	-67.20
943	-18.54	954	-44.03	965	-69.51
944	-20.85	955	-46.34	966	-71.83
945	-23.17	956	-48.66	967	-74.15

5.1: Evaluation of the Effect of Multipath Signals on Received Signal Strength

The effect of varying the number of multipath signals (τ) arriving a particular point,

on the received signal strength ($\chi(t)$) at that point using mat lab simulations are shown in table 5.2 and plotted below

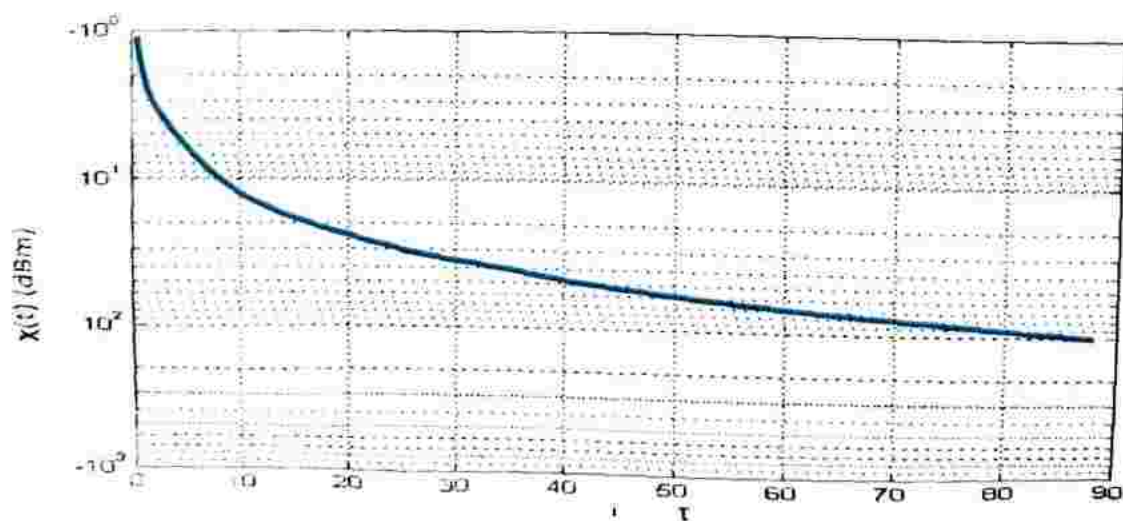


Figure 6: Number of arriving multipath signal Vs Received signal

From the plot it is clear that as the arriving multipath signal increases the received signal strength at that point decreases. Hence signal

fluctuations increases with the increase in the number of arriving multipath signal which result to increase in call interruptions.

5.2: Evaluation of the Effect of Varying the Carrier Frequency on Received Signal Strength

The effect of varying the operational frequency (f_0) of the project model on the received signal

($\chi(t)$) at a particular point using mat lab simulations are shown in table 2 and plotted below

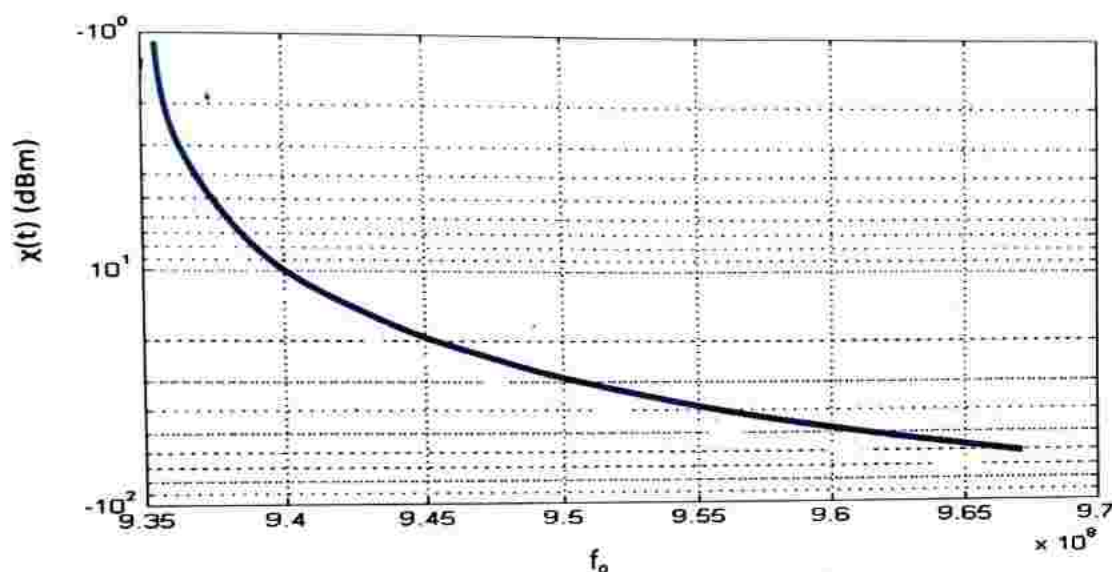


Figure 7: Effect of Varying Carrier Frequencies Vs Received Signal Strength for each Frequency

From the plots, it can be seen clearly that as multipath signal increases received signal level decreases a situation that causes severe changes in cellular network receptions which may lead to intermittent call receptions. Also as transmitting frequency increases received signal level increases. This effect can be applied to mitigate the effect of fading in cellular network environment.

6.0: Conclusion

It has been seen from figure 7 that a slight change in the operational frequency of a cellular signal causes variations in the received signal strength. Thus by changing the transmitting frequency of a GSM system, intermittent signal receptions at any point in the network coverage area can be reduce to a very large extent and in this case with the determination of the appropriate frequency at the point of unsteady reception, frequency band that do not take any part in improving the signal reception as in the case of the conventional method will be eliminated.

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