Coverage Optimization of Eureka Digital Sound Broadcasting Single Frequency Network using Simulated Annealing and Particle Swarm Optimization

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Abstract—**Due to scarcity of bandwidth available for sound broadcasting, Digital sound broadcasting Technology is emerging to be the Technology of resort in sound broadcasting industry towards replacing the analogue sound broadcasting currently dominated by FM Radio. There are many digital sound broadcasting systems being proposed with different performance and bandwidth efficiency. Static delays are artificial delays intentionally introduced at each Transmitter in order to minimize interference in a Single Frequency Network (SFN). In this paper, we have looked at the Terrestrial digital audio broadcasting (T-DAB) system specifically to optimize its final SFN coverage by finding an optimal set of static delays for transmitters. For the sake of simulation, hexagonal model of transmitters operating under Single Frequency Network (SFN) was used. The aim of this study is to maximize SFN coverage by using optimal set of artificial static delays, Particle Swarm Optimization (PSO) have strong ability in finding the global optimistic result while Stimulated Annealing (SA) algorithm has a strong ability to find the local Optimistic result and therefore based on their unique strength, these methods were selected so that our study can have a good comparison in terms of coverage by using both global and local optimistic results. We report the increase of coverage by 1.12% and 2.38% using Simulated Annealing and Particle Swarm Optimization technique respectively.**

Keywords—**Digital audio broadcasting, particle swarm optimization, simulated annealing, artificial static delays**

I. Introduction

The current need of bandwidth for new services especially in audio broadcasting has made the current Technology (Analogue FM) used looks inefficient in bandwidth utilization. The Eureka Digital Audio Broadcasting (DAB) system is a digital system intended to offer reliable digital sound broadcasting for mobile and stationery receivers, using a simple, non-directional antenna. Digital Radio (sound) Broadcasting employs digital modulation and compression techniques to transmit audio programs (music, news, and sports; among others) and is the most widely adopted digital radio standard among the available digital sound systems. One of the advantages of DAB system is that it uses OFDM to facilitate SFN. In a Single-Frequency Network (SFN), the broadcasted signal takes through different paths to reach the receive with different propagation delays creating an "artificial" delay spread[1]. All transmitters send synchronously the same information using the same frequency band and the various signal coming from different transmitters are seen as replicas (echoes) of the same signal and can combine positively if their temporal spread is compatible with the selected guard interval of the OFDM modulation [2]. However, SFN transmission can be considered as a severe form of multipath propagation and interferences may damage the system performance. The single frequency network (SFN) is a popular solution in modern digital audio and television system networks for extending effective coverage, compared to its traditional single transmitter counterpart [3].

In order to achieve large coverage, artificial internal delays can be introduced in each transmitter participating in SFN. Among other factors, the total coverage of SFN can be improved by introducing optimal artificial static delays [4]. The design and introduction of artificial delays can be a more complicated job especially for a large network which involves many transmitters.

This paper focuses on optimal artificial static delay designs for DAB SFN using simulated annealing (SA) and Particle Swarm Optimization (PSO) algorithms aiming to improve the DAB system performance in terms of final coverage achieved.

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The rest of the paper is organized as follows: the Section II describes T-DAB system and its parameters as shown in Table I. Section III describes the SFN network planning where a hexagon model with 19 transmitter sites has been used in this study. Section IV describes the SFN Propagation model used. In Section V, a receiver model is discussed in which a receiver signal weighting functions under different synchronisation strategies are detailed. Section VI discusses the optimization process where simulated annealing (SA) and particle swarm optimization (PSO) techniques have been applied successfully in this study. Section VII discusses the results obtained in this study while Section VIII gives the final conclusion.

II. T-DAB System

The DAB family of standards comprises of Digital Audio Broadcasting (DAB) and its newer version Digital Audio Broadcasting Plus (DAB+) for Terrestrial digital sound broadcasting and Digital Multimedia Broadcasting (DMB) for mobile TV[5]. Digital Audio Broadcasting system is designed such that it is able to operate at all frequencies up to 3GHz for mobile reception (higher for fixed reception) and may be used on terrestrial, satellite, hybrid (satellite with complementary terrestrial), and cable broadcast networks.

In addition to supporting a wide range of sound coding rates (and hence qualities), it is also designed to have a flexible, general-purpose digital multiplex which can support a wide range of source and channel coding options. The DAB system provides a signal which carries a multiplex of several digital services simultaneously. The DAB system bandwidth is about 1.5 MHz, far larger than the 400 kHz of analogue FM. It provides a total transport bit rate capacity of about 2.4 Mbit/s. Depending on the requirements of the broadcaster (transmitter coverage, reception quality), DAB system provides adjustable error protection for each service independently. The DAB system is designed in four modes of operation allowing a wide range of broadcasting frequencies up to 3 GHz. All of four DAB modes are designed such that can cope the situation of Doppler spread and delay spread.

DAB Mode I allows the largest transmitter separation as it have longest guard interval and this is good for terrestrial transmission. Mode II has shorter guard interval and therefore is suitable for local radio and small-to-medium SFN applications. Mode III is a satellite version of DAB and can be used as complementary terrestrial transmission at all frequencies up to 3 GHz. This mode is also the preferred mode for cable transmission up to 3 GHz.

TABLE I. Design Parameters for T-DAB System mode I and II

S/N	DESIGN PARAMETERS	DAB MODE I	DAB MODE II
1	Number of carriers	1536	384
2	Carrier spacing	1kHz	4kHz
3	Useful Symbol duration (Tu)	1000µs	250µs
4	Guard interval (Tg)	246 µs	62 µs
5	Total symbol duration (Ts)	1246 µs	312µs
6	Transmitter power	1Kw	1Kw
7	Height of Transmitter	60m	60M
8	Maximum Tx separation	75km	24km
9	Receiver sensitivity	-90dBm	-90dBm
10	Receiver Height	1.5m	1.5m
11	Centre frequency	200MHz	200MHz

The fourth mode termed as Mode IV is designed to operate between Modes I and II and is also optimized for operation at 1.5GHz. The mode has a provision for longer delays for simplicity in SFN implementation. Table I presents the design parameters for both DAB Mode I and II as detailed in [6].

Above of all, Digital audio broadcasting system and its versions (DAB/DAB+) use orthogonal frequency division multiplexing (OFDM) which allows the system to be operated in SFN. The T-DAB specification offers guard interval of 1/4of the active symbol duration as it can be seen in Table I.

A commercial operation of DAB+ has been launched in several countries includes Australia, Hong Kong, Indonesia and United Arab Emirates (UAE) in 2009, 2011, 2016 and 2018 respectively. However, some other countries have launched DAB+ trials include Vietnam in 2013 with other trials planned for 2017, Myanmar who started their trials in 2016, Thailand in 2018 [6]. In Africa as a continent of interest, Tunisia and South Africa are some of the countries that have so far conducted DAB trials [7].

III. SFN Planning

A single frequency network (SFN) requires that all participating transmitters synchronized in frequency and time so that the receivers in the coverage area may receive signals coming from different transmitters within the guard interval.

It is required that every transmitter broadcast using the same frequency and broadcast like OFDM symbol equal time for all transmitters. “GPS Timing Receivers”, or “GPS Disciplined oscillators”, GPSDO, is used to provide a timing signal from an internal quartz oscillator controlled by an algorithm relying on the timing of the GPS system[8]. Each symbol is label with a GPS synchronization time stamp (STS) stamp and maximum network delay parameter. Since the symbols reaches the transmitters in SFN using different network routes, each transmitter will compute the transmission time of each OFDM block. The accuracy of 10 MHz will guarantee any transmitter belonging to one SFN cell to broadcast exactly the same set of sub-carriers (same frequency, no frequency shift) [9]. Consider the SFN which involves four transmitters with different network delay from SFN adaptor as shown in Fig. 1 for the purpose of illustration.

Fig. 1 shows an OFDM symbol sent to four transmitters using different routes with different network delays. The transmit time of symbol depends on GPS synchronization time stamp (STS) and maximum Network propagation delay. From the figure, Transmitter two (T2) received the OFDM symbol earlier than other transmitters, for synchronization purpose, T2 has to wait until the transmit time is due before it transmit the symbol. Transmitter three (T3) received an OFDM symbol late than other transmitters but within maximum network delay time and therefore it has to wait for a short time before it transmit the symbol. However, Transmitter four (T4) received an OFDM symbol late (after network delay time expired), this transmitter will cause interference in the network if it is allowed to transmit.

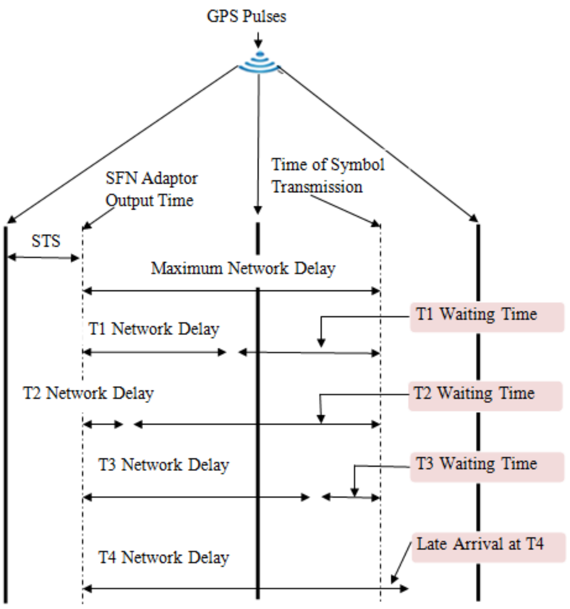

Figure 1. OFDM Symbol synchronization at each transmitter in SFN.

When an SFN is deployed, it is expected to provide services using a single channel within the whole service area. In some cases, this service area can be as large as an entire country [10]. The time of transmitter to delivers each OFDM symbol can be delayed to a certain percentage of the guard interval [11]. The theoretical model of OFDM receivers T-DAB, under SFN conditions, supposes that the total amount of received signals within the guard interval at the receiver will be contributing to the total usable signal strength and the signal coming from transmitters whose relative delay with respect to FFT window synchronization exceeds the guard interval will be contributing to the overall interference.

Among other factors, SFN coverage can be optimized by imposing an artificial static delay at each transmitter in order to find the optimum relative delay combination that maximizes the useful signal strength and minimize interferences at the receivers' sites.

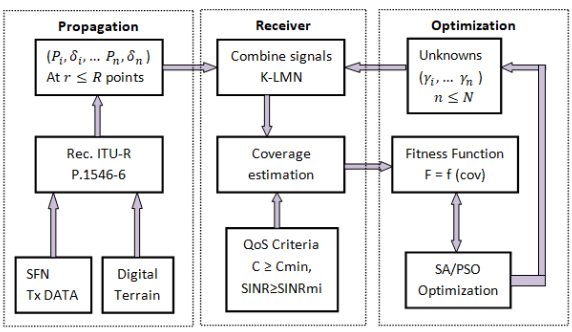

Figure 2. Block diagram for T-DAB SFN optimization model.

The ITU-R P1546-6 Recommendation[12]gives a technique for prediction of point-to-area radio propagation in the frequency range 30MHz to 4000MHz. This recommendation was used in this study as shown in Fig. 2.

IV. SFN Propagation Model

Looking at a SFN consisting of a set of *N* number of transmitters whose power ($P_1 \dots P_n$) at the receiver location and propagation delays vector ($\delta_1 \dots \delta_n$) are known. Each transmitter in the network will be contributing a portion of the received signal at each receiver. Two prediction methods which are ITU-R P.1546-6, P.1812 and the propagation by diffraction models of the ITU-R P.526 have been considered [12, 13].

In this study, a MATLAB software was used in which a SFN hexagon propagation model shown in Fig. 3was designed where nineteen (*N*=19) transmitter sites (for the purpose of simulation in MATLAB) spaced at 73km (DAB Mode I) were involved. The guard interval time of DAB Mode I (246 µs from Table I) was used to limit the Transmitter site spacing to avoid symbol interference.

Figure 3. SFN Transmitter hexagonal model.

The service area to be covered was subdivided into tiny receive locations in which a receiver was placed in each location for coverage measurements as shown in Fig. 4.

Figure 4. Receiver locations in the coverage area.

Signal strengths (Pi,$1 \leq i \leq N$) and signal propagation delay (δi, $1 \leq i \leq N$) from all N participating transmitters were recorded at each all receiver locations ($1 \leq r \leq R$).

V. Receiver Model

SFN transmission is a nearly severe form of multipath signal propagation. Under this consideration therefore the multipath signals received at each location have to be considered to optimize network gain and maintain the spectrum efficiency [14].

Depending on propagation duration of each signal at the receiver, the signal can contribute full or partially to the received power or interference. Based on the time instant in which each signal arrives at every receiving location, the receiver mask weighs up the completely or partially contribution of each signal to the useful and interfering components. For T-DAB, the method for splitting the received signal power into interfering component and useful component is as expressed in Eq.(1)[15]. The total effective useful signal power is as given in Eq.(2) while the total effective interfering signal power is as given in Eq.(3).

$$w_i = \begin{cases} 0 & if t \leq -T_u \\ \left(\frac{T_u+t}{T_u}\right)^2 & if -T_u < t \leq 0 \\ 1 & if\ 0 < t \leq T_g \\ \left(\frac{T_s-t}{T_u}\right)^2 & if T_g < t \leq T_s \\ 0 & if t \geq T_s \end{cases} \quad (1)$$

$$C = \sum_i w_i C_i \quad (2)$$

$$I = \sum_i (1 - w_i) C_i \quad (3)$$

where

C_i is the signal power contribution from the i-th transmitter.

C is the total effective useful signal.

I is the total effective interfering signal power

W_i is the weighting coefficient for the i-th component.

T_u is the useful symbol length.

T_g is the guard interval length.

VI. FFT Window Synchronisation

Optimal positioning of the FFT window in multipath reception is very important so that signals arriving at a particular receive point can contribute constructively in the reception of a particular symbol. There are many receiver synchronisation strategies in the literature each with its advantages and disadvantages. To analyze the performance of the SFN model, in this study, three different synchronisation strategies which are Centre of Gravity (C.G) strategy, Strong Signal (S.S) strategy and First Signal above threshold strategy (S.H) has been used.

A. Centre of Gravity (C.G) Strategy

Under this strategy, the impulse response at the receiver is used to calculates the 'centre of gravity' the FFT-window is centred on that point in time as it shown in Fig. 5. The calculation for centre of gravity is done using Eq.(4) and the result is as illustrated in Fig. 5.

$$t_c = \frac{\sum_i p_i t_i}{\sum_i p_i} \quad (4)$$

where

t_c = centre of gravity

p_i = power of the i-th signal

t_i = time of the i-th signal

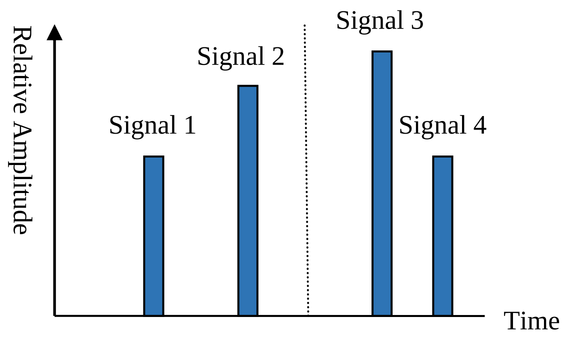

Figure 5. Centre of Gravity synchronization strategy.

B. Strongest Signal (S.S) Strategy

The idea here is to synchronize the FFT-window to the strongest signal. From Fig. 6, it can be observed that the strongest signal is signal 3 and therefore the FFT-window positioned to it[16].

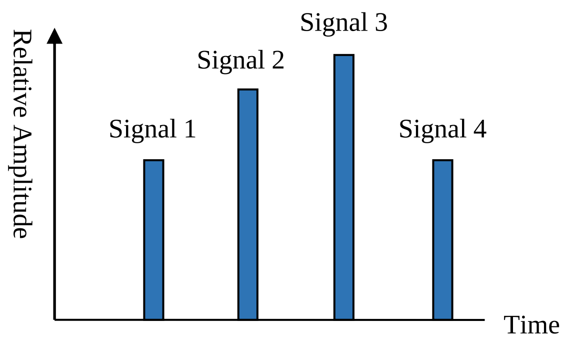

Figure 6. Strongest signal (signal 3) synchronization strategy.

C. First Signal above Threshold Strategy (S.H).

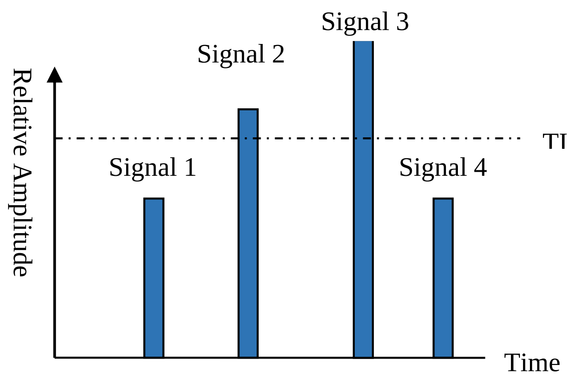

Figure 7. First signal above Threshold (signal 2) synchronization strategy.

Under this strategy, the FFT window is synchronised to the first signal which is above a predetermined level. In this study, the receiver threshold was set to -97.7dBm as a requirement for T-DAB reception [16].From Fig. 7 it can be observed that Signal 2 is the first signal with power above threshold and therefore the FFT-window is synchronised to it[6].

After choosing the synchronization strategy and applying receiver signal mask in Eq.(1), the aggregate of useful power *C*, and interfering power *I* at each receiving location can be determined using power sum, k-LNM or t-LNM (v2) combination. In this study, the lognormal method k-LNM was used. The k-LNM (k=0.7) or t-LNM (v2) methods, which assume a log-normal distribution of the field strength are more accurate than the power sum method, based on a non-statistical summation of the individual signals [17]. The combining process is done as shown in Eqs.(5–12)using the following steps

1) The power and static delay Fi, σi, i = 1, ...,n of each transmitter to a particular receiver is converted to Nepper scale using Eq.(5).

$$X_{Neper} = \frac{1}{10\times\log_{10}(e)} \times X_{dB} \quad (5)$$

2) The mean values $M_i$and the variances Si of the n power distributions is evaluated using Eqs.6 and 7.

$$M_i = e^{F+\frac{\sigma_i^2}{2}} \quad (6)$$

$$S_i^2 = e^{2F+\sigma_i^2} \times (e^{\sigma_i^2} - 1),\ i = 1 \ldots n \quad (7)$$

3) Determine mean value M and variance S2 of the sum power distribution:

$$M = \sum_{i=1}^{n} M_i \quad (1)$$

$$S^2 = \sum_{i=1}^{n} S_i^2 \quad (2)$$

4) Determine the distribution parameters F_Σ and σ_Σ of the approximate log-normal sum distribution:

$$\sigma_\Sigma^2 = \log_e\left(k\frac{S^2}{M^2} + 1\right) \quad (3)$$

$$F_\Sigma = \log_e(M) - \frac{\sigma_\Sigma^2}{2} \quad (4)$$

Transform$F_\Sigma$andσ_Σ from Nepper scale to dB scale:

$$X_{dB} = 10 \times \log_{10}(e) \times X_{Neper} \quad (5)$$

Once the signals have been combined at each receive point, *CINR*, can be estimated for each receiving location ($1 \le r \le R$) as given in Eq.(13).

$$CINR_r = \frac{\sum_i P_i w_i(\delta_i - \delta_o)}{\sum_i P_i[1 - w_i(\delta_i - \delta_o)] + N_o} \quad (6)$$

VII. Optimization Process

The final coverage and associated performance of an SFN is a joint result of the properties of all transmitters in the SFN. Due to the large number of parameters involved in the process, finding the right configuration is quite complex [10]. The optimization process is carried out to find the maximum coverage possible which can be provided by the combination of transmitters participating in SFN. The time of each transmitter to delivers each OFDM symbol to a receiving point can be adjusted to a certain percentage of the guard interval.

Besides the choice of the Guard Interval, Modulation and Code rate, other parameters like static delay of each SFN transmitter, power of transmitters, antenna diagrams and site selection can be used to optimize a SFN. Static delay is an easier parameter to be optimized and in this study, artificial static delay for each transmitter is optimized to attain optimal coverage. The static delay imposed on each OFDM symbol at the transmitter is less or equal to the OFDM guard interval time. Due to many number of transmitters involved, a process of static delay adjustment can be very complicated and tidies job for planning engineers as it involves a lot of trial and errors. This can be easily handled by using optimization algorithms. In this study, simulated annealing and particle swarm optimizations has been used to find the optimal static delay for each transmitter involved in SFN network.

A. Simulated Annealing

The Simulated Annealing (SA) is an optimization technique which was conceived from the idea of cooling of a heated metal that evolves from a single solution without retaining past or recent information about the process [4].

The concept of simulated annealing was first published by Metropolis *et al.* in 1953 [18]. The process known as annealing, in metallurgy is a technique which involves heating and controlled cooling of a material to increase the size of its crystals and reduce their defects [19] and therefore, SA technique simulates the annealing of a heated metal by emulating the changes of energy contained as the temperature is slowly lowered until when the equilibrium is reached. For each iteration $i \rightarrow i{+}1$, the fitness function (F) (Eq. 15) is evaluated using the new temperature (solution vector (V)).

After the fitness function is evaluated, if the fitness function decreases then the new solution is deemed to be approaching to the minimum value of energy and this is deemed to be better solution and accepted. If not that then, *if* $F \ge 0$, according to Metropolis criterion, the probability function in Eq.(14) has to be used to judge whether or not the new vector $Vi{+}1$ is to be selected.

$$BPD(V_i - V_{i+1}) = \begin{cases} \exp\left(-\frac{\Delta F}{T_a}\right) & if\ \Delta F \ge 0 \\ 1 & if\ \Delta F < 0 \end{cases} \quad (7)$$

Simulated Annealing has been used in many optimization projects including those in the area of Telecommunication Engineering. In this study, SA optimization process was done using MATLAB and the end solutions (static delays) in Table II from the optimization algorithm were used to evaluate the fitness function in Eq.(15)which was described as a minimization problem.

The fitness function used in this study is given in Eq. (15) where *uCov* represents the number of uncovered points in the targeted area.

$$F(uCov) = \sum_{i}^{N} uCov_i \quad (8)$$

$$uCov_i = \begin{cases} 1 & if\ C_i < C_{min} \\ 0 & else \end{cases} i = 1 \dots N \quad (9)$$

The optimization process considered three different receiver synchronisation strategies as detailed in part 6. Coverage indicates the percentage of receiver locations in which ***C>Cmin***. Furthermore, ***Cmin= -97.5 dBm*** as the threshold value has been used to decide whether a receiver location within the study area is covered or not. Table III and Fig. 8 give the results of SA optimization in which among the number of receive locations (3025), less were covered without any optimization technique using three different synchronization strategies. From the Table, it can be clearly seen that there is an increase of receive location covered after optimization process.

TABLE II. STATIC DELAYS FOR EACH TRANSMITTER IN SFN AS A RESULTS OF SA OPTIMIZATION

Tx	C.G (µ Sec)	S.S (µ Sec)	S.H (µ Sec)
1	38.2	17.3	71.6
2	111.9	30.9	60.0
3	67.7	53.1	62.1
4	105.5	182.9	84.8
5	35.0	33.6	85.1
6	55.2	32.7	62.5
7	13.3	206.3	47.0
8	168.6	69.4	61.4
9	73.6	214.7	49.2
10	111.3	207.1	63.8
11	174.0	65.3	150.5
12	212.4	242.1	80.8
13	101.1	213.6	49.3
14	175.5	198.7	56.6
15	187.5	217.6	62.4
16	138.8	192.2	68.7
17	116.0	182.1	63.1
18	156.4	227.4	100.3
19	119.2	176.5	63.2

TABLE III. RECEIVE LOCATIONS COVERED AFTER SA OPTIMIZATION

S/N		1	2	3
Number of Locations		3025		
Synchronizations strategy		C.G	S.S	S.H
Total number of covered locations	Initial	2781	2817	2455
	%tage	91.93	93.12	81.16
	SA	2787	2859	2489
	%tage	92.13	94.51	82.28
	ΔC	0.20	1.39	1.12

B. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is another optimization technique used in this study for the aim of obtaining optimal coverage in the area where the SFN hexagonal model was deployed. This algorithm optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search space according using simple mathematical formulas. Particle Swarm Optimization (PSO) is among the most universally applied population-based heuristic optimization algorithms. PSO has been successfully used in various scientific fields, ranging from humanities, engineering, chemistry, medicine, to advanced physics [20]. Solutions in PSO are represented as particles and these particles hold two vectors, i.e., ***position vector and velocity vector***, rep- resenting the particle's evolutionary state in the search space [21].

Again, the optimization process using PSO was done using MATLAB and the results of static delay for each transmitter in SFN are given in Table V. Table IV and Fig.9 gives the results of covered receive locations after PSO optimization of static delays for each transmitter in SFN.

TABLE IV. RECEIVE LOCATIONS COVERED AFTER PSO OPTIMIZATION

S/N		1	2	3
Number of Locations		3025		
Synchronization strategy		C.G	S.S	S.H
Total number of covered locations	Initial	2781	2817	2455
	%tage	91.93	93.12	81.16
	PSO	2791	2873	2527
	%tage	92.26	94.96	83.54
	ΔC	0.33	1.84	2.38

The optimal static delays obtained after particle swarm optimization are as shown in Table V.

TABLE V. STATIC DELAYS FOR EACH TRANSMITTER IN SFN AS A RESULTS OF PSO OPTIMIZATION

Tx	C.G (µSec)	S.S (µSec)	S.H (µSec)
1	0	4.2	62.9
2	53.2	2.7	33.5
3	58.2	0	94.4
4	39.8	3.9	55.6
5	15.9	58.6	95.2
6	19.5	12.9	61.5
7	26.0	10.9	43.5
8	245.1	0	31.2
9	104.5	245.4	19.2
10	167.1	246.0	89.6
11	245.9	154.7	237.7
12	232.9	245.3	78.8
13	189.6	242.2	23.8
14	85.1	241.7	25.7
15	200.2	26.8	44.1
16	36.6	237.3	129.2
17	55.6	229.5	159.2
18	246.0	0.5	51.9
19	218.6	243.7	29.3

VIII. RESULTS AND DISCUSSION

Figs. 8-9 compare the number of covered receive location before and after SA and PSO optimizations respectively. Figs. 11-12 gives the best function value of the objective function for both SA and PSO respectively. From these figures, it can be clearly observed that heuristic optimization techniques gives better performance as the number of covered receive locations increased. Using different synchronization strategies it can be observed that by dealing with static delay only, the coverage of SFN was improved by 1.4 to 2.4 percentages as summarized in Table III and IV.

In this study, simulated annealing and particle swarm optimization techniques were used and their optimization efficiency was compared. From Figs. 10-14, it can be observed that PSO seems to have better results than SA. This is due to larger number of swarm particles involved in the search.

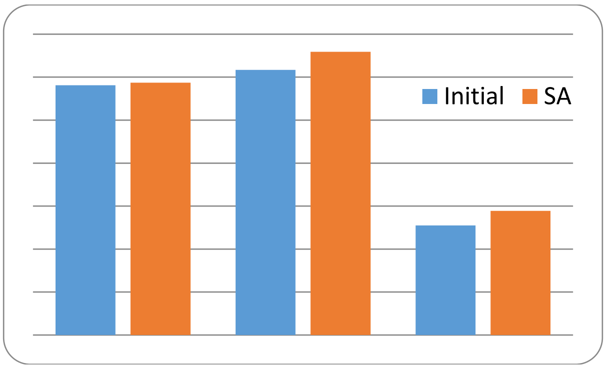

Figure 8. Number of receive locations covered before and after SA optimization.

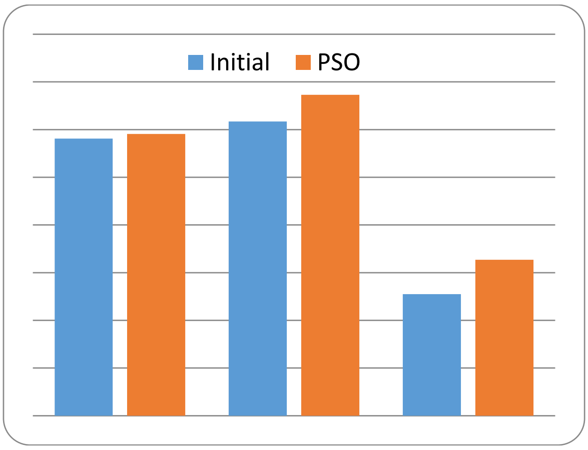

Figure 9. Number of receive locations Covered before and after PSO optimization.

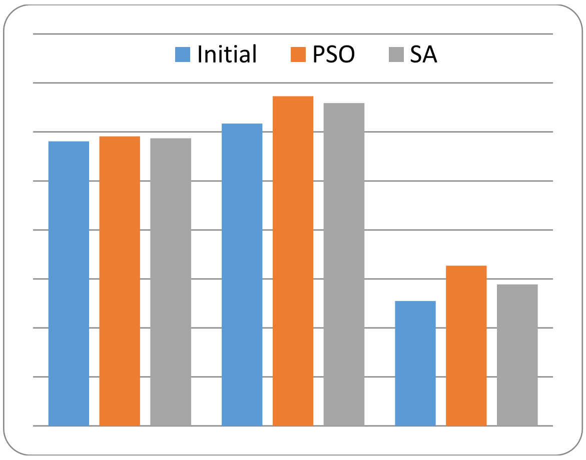

Figure 10. PSO and SA performance in static delays optimization for SFN.

It can be observed that, from Figs. 13–14, different synchronization schemes proposed different length of static delays. Simulated Annealing (SA) gives longer static delay under strong signal synchronization (S.S) strategy with average of 145.45µsec. Besides that, synchronization using first signal above threshold (S.H) seem to have lower static delay with average of 70.65 µsec. On the other hand, using PSO, Centre of Gravity (C.G) strategy seems to have longer static delays with average of 117.9µsec. Synchronization using first signal above threshold (S.H) seem to have lower static delay with average of 71.9 µsec.

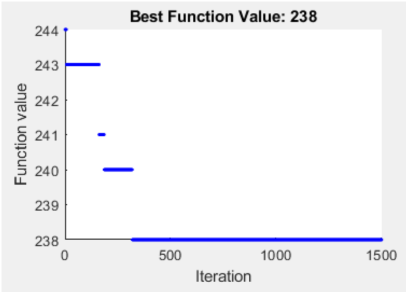

Figure 11. Best Function values using SA optimization.

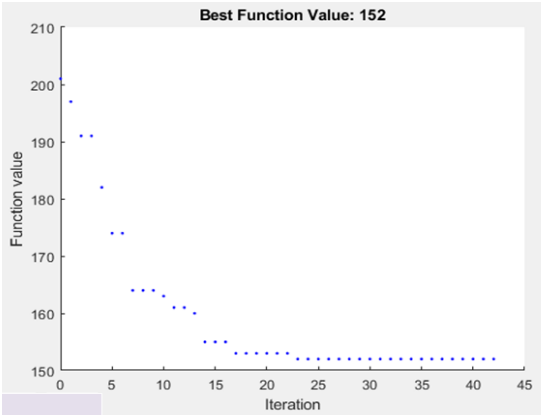

Figure 12. Best Function values using PSO optimization.

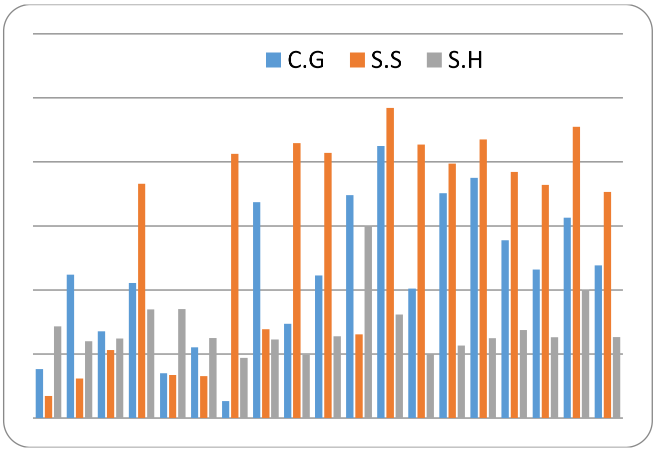

Figure 13. Static delay results comparison using SA under different synchronization strategies (µsec).

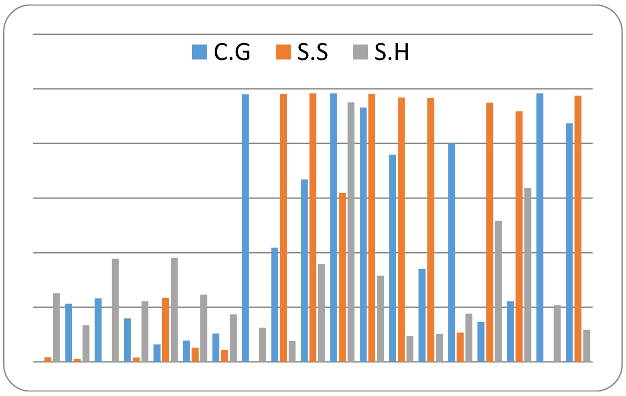

Figure 14. Static delay results comparison using PSO under different synchronization strategies (µsec).

IX. Conclusion

This study involved two heuristic optimization algorithms which are SA and PSO aiming at maximizing coverage of mode I of Eureka Digital Sound Broadcasting Single Frequency Network (SFN) by imposing artificial static delay at each transmitter in the network. PSO and SA schemes were applied at the same conditions of static delay for each Transmitter. As shown in Tables III and IV, the increase of covered receive location is up to 1.4% using SA and up to 2.4% using PSO. Both optimization algorithms present the capability to increase overall coverage and reduce interference by optimal adjustment of static delay at each Transmitter. However, PSO algorithm appeared to have better optimization results (2.4%) as compared to SA (1.4%). In this study, we consider static delay as the only parameter that can be adjusted to obtain maximum coverage. However, other parameters like transmitter power and positions, antenna gain and position need to be studied too.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

All the Authors participated in the preparation of this paper, Joseph Sospeter Salawa did the model preparation, wrote all the MATLAB codes and simulation. Elijah Mwangi advised on the newness of the references and checked the format and English grammar of the paper. Nerey Mvungi I checked English grammar, he also participated in making sure that the latest paper was submitted on time.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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