Compensated Modeling of Taguchi Method and Genetic Algorithm Based on RSSI of DSRC Communication

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ABSTRACT

The automotive industry is moving aggressively in the direction of advanced active safety. Dedicated Short Range Communication (DSRC) is a key enabling technology for the next generation of communication-based safety applications. Distance measurement based on RSSI, featuring low communication overhead and low complexity, is widely applied in the ranged-based localization of DSRC communication. However, the uncertainty factor and ranging error of shadowing model are varied under different circumstances. Furthermore, the drawback of positioning error will affect its priority in geocasting or multi-hop of DSRC signals. This paper presents an operational scheme of parameters contribution design by utilizing Taguchi method, and the experiment inference is redesigned to compensate circumstance factors for shadowing model using genetic algorithm in proving ground of ARTC. The objective of Taguchi design is to optimize the mean and minimize the variability that results from uncertainty represented by noise factors. The channels of scheduled experiments utilized 5.9 GHz for the entire packet duration, and Taguchi analysis result shows the system parameter contribution under signal to noise ratio. The genetic algorithm provides advanced solution to circumstance factor and measured uncertainty using minimal absolute error. These results may serve as benchmarks of parameters design for future DSRC channel communication.

Keywords: Dedicated short range communication, Receive signal strength indication, Taguchi method, Genetic algorithm.

I. INTRODUCTION

The DSRC standard was established at 5.9 GHz band for vehicle-to-vehicle and vehicle-to-roadside communications in 1999. Currently, the DSRC is being developed by workgroup of IEEE 802.11p [1] and allocated 75 MHz at 5.9 GHz. The United States Department of Transportation (USDoT) has been considering DSRC for accident prevention, intelligent transport systems, open road tolling, and electronic payment systems [2-3]. The primary purpose is to enable public safety application and the private services are permitted to lower cost and encourage its development.

Since the inception in LAN standard, the wireless communications market has been growing rapidly, which gives the location-based services and applications provide a broad market space. In low cost positioning research and development, the common approach is to establish small scale indoor environments positioning network [4]. Positioning methods currently used mainly divided into two categories: distance-based location algorithm and the algorithm without. Algorithm based on distance between nodes by measuring the distance and relative angle, the use of trilateral relation, triangulation or other positioning is the maximum likelihood estimation algorithm. Ranging technology used to receive signal strength indication (RSSI), time of arrival (TOA) and angle of arrival (AOA) [5]. The RSSI-based ranging technology is the most popular method that requires less overhead and low implementation complexity in recent years.

However, the state is more varied in the radio propagation conditions. Typically the transmitted signal through the multipath propagation to reach the receiver, so the multipath effect will cause the received signal envelope and phase change in non-direct signal component and the direct signal component composed of a combination in terms of the relative emission signal distortion. As the environment is complex and it reflects a lot of signals in any selected communication path, the path loss is correspondingly different and path loss leads to great difficulties. In order to overcome the aforementioned problems, Taguchi's method for experiment design is proposed to find parameters effects.

In this paper, the DSRC signal transmission parameters optimization meets specific environmental parameters using Taguchi analysis. The compensated model uses genetic algorithm to provide optimal parameters.

II. SYSTEM ARCHITECTURE

A. System Configuration

The research platform is built on both vehicles, and the test campus is located in general performance test track of ARTC proving ground in Fig. 1. This example is simulated metropolitan area in DSRC signals broadcasting. The application usually uses DSRC signals to provide driving assistance information (about vehicle accidents, obstacles in the road, etc) and traffic information (a map of the surrounding area, the presence of traffic jam).

The test track will be divided into several segments

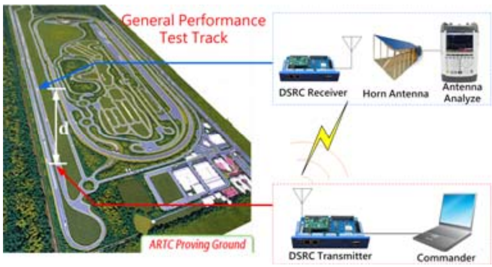


Figure 1: System operation platform.

every 10 meters. To transmit DSRC signals with different packets speed, packet sizes and packet length, the commander plays a role with embedded channel switch, packet slicing and power control programs. The receiver is used to receive packets from transmitter, and furthermore, the horn antenna is the key research tool for measuring environment power spectrum density. The measurement result is shown in antenna analyze which located in receiver vehicle. The DSRC receiver is used to check transmitting data and packet availability.

B. System Requirements

The DSRC device is developed by Industrial Technology Research Institute whether the receiver or transmitter device located in vehicle. Besides, the hardware satisfied industry standard. Besides, the software can control packet TX/RX operations in different channels for different application.

As shown in Fig. 2, the frequency spectrum of DSRC is divided into seven wide channels (10MHz). Channel 178 is the control channel (CCH), which is restricted to safety communications only. CCH is a unique channel shared with all WAVE devices and used for control communication. The two channels at the edges of the spectrum are reserved for future advanced accident avoidance applications and high powered public safety usages. The remainder is service channels (SCH) which are available for both safety and non-safety usage, and SCH is used for normal data communication. In resource management, security services, network services and medium access control, the hardware is based on IEEE 802.11p standard to WAVE protocol or IEEE 1609.1 to 1609.4.

C. Problem

In DSRC communication, the priority usually is based on distance likelihood estimation. The DSRC device can be used to receive signal strength indication (RSSI) to mark a location in the RF signal strength [6-7]. In general, the RSSI will decay with increasing distance. This intensity decay, as the signal propagation loss, it is related to the environment reflection. According to the received signal strength, the use of theoretical and empirical propagation loss model, transmission loss can be converted into the distance. The following Eq. (1) is a logarithmic normal distribution of propagation loss model, named as shadowing model.

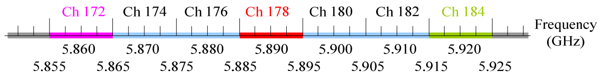


Figure 2: DSRC frequency allocation.

$$\overline{[p_r(d)]}_{dbm} = \overline{[p_r(d_0)]}_{dbm} - 10n\log(\frac{d}{d_0}) + X_{dbm} \quad (1)$$

In Eq.(1), the d_0 is specified distance, usually 1m, and the $\overline{[p_r(d_0)]}_{dbm}$ is receiver RSSI which its distance is located in d_0. The symbol $\overline{[p_r(d)]}_{dbm}$ is receiver RSSI which its distance is located in d. The n is path loss constants, and the value is relied on environment and building. $X_{dBm}$is masking factor, and the mean value is 0 and has low variance whose quality is gaussian distribution.

Under different circumstances, the values of X_{dBm} and n are varying. The masking factor usually affects its power decaying and measuring error, and n has larger impact on path loss propagation. The following discussion will focused on DSRC parameters configuration, and Taguchi method is the solution to find out crucial ratio distribution. The result will give a benchmark for parameters configuration of DSRC communication. From orthogonal array, the purpose of this paper provides optimized parameters learning using genetic algorithm. The experimental plan is to determine all of the available cases under present parameters configuration. The demonstrated distance is divided into ten segments every 10 meters.

III. THE ANALYSIS OF TAGUCHI METHOD

To clarify parameters distribution and meet better efficiency, Taguchi method is adopted in this study. Taguchi methods are used widely as the basis for development trials during industrial process design [8], principally in development trials, where they are used to generate enough process information to establish the optimal conditions for a particular process, using the minimal number of experiments possible. The parameters configuration of DSRC communication has three factors, including bit rates, power density, packet sizes and number of packets. Each factor also has three levels which these selected values are common applied and limited ability in DSRC application, as shown in Table I. Such as bit rate, the typical bit rate is least 3 Mbits. The standard of packet sizes is according to maximum length of OSI network layer under 1024 bytes.

Due to four factors and three levels, the Latin squares uses $L_9(3^4)$ orthogonal array [9]. Number of experiments is nine times with selected parameters design. In normal operation, number of experiments should be done at least 81 (i.e. 3×3×3×3) times. But Taguchi method has large reduction with statistical distribution. Taguchi uses a number of progressive trials. An initial experiment is often used to examine many factors in order to identify those that have a major effect. These 'control factors' are then used to predict a combination that will lead to optimal performance. If these results are satisfactory then further experiments are unnecessary.

Fig. 3 showed the hardware setup in system operation, and each transmitter or receiver uses two antennas to transmit or receive packets. The middle of Fig. 3 used horn antenna to do objective measurement, and the right side device is spectrum analyze which measured the power density of RSSI. The measured result is shown in spectrum screen and output data which is processed for mean value with linear scaling integration method. Fig. 4 showed the part result of experiments, and furthermore some figures presented disorder level power spectrum, such as the right part of Fig. 4

Figure 3: System allocation and horn antenna with analyzer.

Figure 4: Power Spectrum under diff. power & packet parameter.

Table I: Factors and its levels.

Control Factors	Levels		
	Level 1	Level 2	Level 3
A. Bit Rate(Mbits)	3	12	27
B. Power Density(dBm)	12	15	18
C. Packet Size(bytes)	64	256	1024
D. Number of Packets	1000	6000	10000

Table II: Orthogonal array

Calculation Numbers	Factors				RSSI (dBm)	Power Distance (m)	S/N
	A	B	C	D			
1	1	1	1	1	-95.2	104.33	12.7
2	1	2	2	2	-87.4	89.7	20.2
3	1	3	3	3	-86.8	99.4	4.4
4	2	1	2	3	-95.1	104.33	12.7
5	2	2	3	1	-91.6	101.2	1.58
6	2	3	1	2	-87.2	105.6	15.0
7	3	1	3	2	-95.3	104.33	12.7
8	3	2	1	3	-90.8	95.2	13.6
9	3	3	2	1	-85.7	93.6	16.1

TABLE III: ANOVA

factors	f	S	V	S’	ρ%
A	2	29.16*	--	--	--
B	2	1.54*	--	--	--
C	2	165.58	82.79	153.28	58.2
D	2	66.99	33.49	54.69	20.8
e	1	0.03*	--	--	--
(e)	5	30.73	6.14	55.314	21
T	7	263.3	--	263.3	100

To meet an optimal and quantitative design with signal to noise ratio, the orthogonal array is operated under fixed distance. The orthogonal array $L_9(3^4)$ is satisfied the selected factors and levels with low interaction. The DSRC communication is too complicated to separate each weighting influence. The advantage of $L_9(3^4)$ has the characteristics of uniform distribution on interaction. The experiment result was test and calculated in Table II with shadowing equation auxiliary. In prior test and experiment design, the related parameters are selected as constant values to analysis its trend with parameters change.

A quality loss or mean square deviation (MSD) function is used to calculate the deviation between the experimental value and the desired value using Eq. (1)-(2). The type of MSD is nominal-the-best where y_i represents the normalized quality loss using shadowing model. The analysis of variance (ANOVA) for DSRC packets is shown in Table III, where it consists of freedom (f), sum of squares (S), sum of mean squares (V), partial sum of squares (S’) and contribution (ρ). Analysis in design of experiments refers to the calculations that are done with results after experiments are carried out.

$$MSD = s^2 = \left(\frac{1}{n}\right)\sum_{i=1}^{n}(y_i - m)^2 \tag{2}$$

From TABLE III result, the mainly impact are packet sizes and packet length under available transmitting condition. The error (e) is the total S/N values and subtracts of four factors. The integration error ((e)) is the summation of error and low SN. The optimal condition would be used to parameters learning, and the combination is bit rate (12 Mbits), power density (15 dBm), packet size (1024 bytes) and number of packets (1000), where it is the integration result from ANOVA and S/N.

IV. COMPENSATED MODELING OF GA

A genetic algorithm, a well-known numerical method, is widely applied in different areas of optimal studies. It is found that if the solution search space is wide or if the selected fitness function is highly nonlinear, the GA’s solutions can strongly depend on the set parameters, which include population size, crossover rate, mutation rate, and the remaining size of the parent [10]. From Taguchi method, these experiments are used to do parameters learning and test patterns. With parameters change, these test patterns are presented overall area cases with worse cases pattern. The following step is focused on parameter learning in ARTC, and the parameters are calculated by minimal square error (MSE).

A. Flowchart of GA

The GA imitates the natural processes of the evolution of genes to develop an algorithm of stochastic search for optimal values, which differs from other methods such as at the initially random guess. The populations are encoded as binary codes, like chromosomes, in which each bit is called a gene; and each population represents a set of solutions of the problem. The offspring are generated through the procedures of crossover, mutation, and selection of chromosomes, as shown in Fig.5. The other kind of population is coding by real values [11-12].

The attraction of the GA is its simple manipulation; and the GA calculation has two main parts. The genetic operation, that is, the chromosomes' crossover and mutation; the evolution operation or reproduction selection, that is, the genetic operation that imitates the procedures of genetic inheritance to create a new generation called the offspring. The evolution operation comes from the evolutionism which selects a new generation on the basis of the fitness of the offspring. The operations of GA include crossover, mutation and selection. On the other hand, real values GA are operated in similar method with different coding [13-14].

B. Crossover of GA

Crossover is the main procedure of chromosomal exchange in the GA because the process relies on chromosomal crossover to achieve an effective database of knowledge. The crossover process combines the characteristics of two chromosomes to generate offspring. At first, a cut point is chosen randomly; the left part of this cut point joins the right one of the other chromosome to form new chromosomes, and vice versa. The number of populations that crossover is determined by the crossover rate P_c, which represents the crossover probability of the population in each generation, i.e., $P_c \times P_o$ crossovers occur, where P_o represents the original population size. When P_c is set too high, the possible search space becomes very broad and results in time consuming searches in a suboptimal solution space. Fig. 6 shows the operation pseudo-code about the concept of cut point.

C. Mutation of GA

Mutation plays a secondary role in the GA; it complements the procedures of crossover and selection. When the population converges to a unique value, the mutation only gives a chance to find a more optimal solution. The determination of whether mutation will occur is decided by the mutation rate (P_m). If Pm is set too low, the potential optimal population may be missed and the suboptimal solution is found. If P_m is too high, similarity and historical inheritance from the parent will disappear.

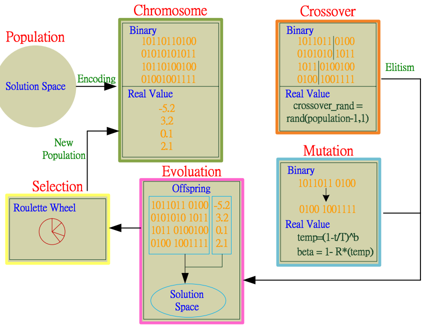


Figure 5: Flowchart of genetic algorithm.

```
function [new_pop] = crossover(population, n_pop,bit_length,target,... probability);

// Calculate cumulative bit_length for crossover
for (i=0;i<n_parameter;i++)
    Cumulative_bit_length(i) = Cumulative_bit_length(i-1)+bit_length(i);

if(Elitism == 1){
    crossover_rand = rand(n_population-1,1);
    new_pop (n_population,:) = population(position_max,:);
}else
    crossover_rand = rand(n_pop,1);

//crossover probability
for ( i=0;i< n_population-1;i++)
    if( (cross_min <= crossover_rand(i)) && (crossover_rand(i) <= cross_max) ){
        crossover_flag = crossover_flag+1;
        cross(crossover_flag,:) = population(mate(i),:);
}
    else
        non_crossover_flag = non_crossover_flag+1;
        non_cross(non_crossover_flag,:) = population(mate(i),:);
// Crossover
for j=1:n_parameter
    cut_point = cross_point(i,j) + Cumulative_bit_length(j);
    new_pop (2*i-1,(cut_point+1):Cumulative_bit_length(j+1))...
                = cross(2*i,(cut_point+1):Cumulative_bit_length(j+1));
    new_pop (2*i,(cut_point+1):Cumulative_bit_length(j+1))...
    cross(2*i-1,(cut_point+1):Cumulative_bit_length(j+1));
end
```

Figure 6: Pseudo-code for Crossover operation.

```
function [population] = mutate_Real(new_pop,n_pop,n_parameter,Elitism,...);

// Jump Mutation
  for i=1:n_population
   if( (mutate_rand(i) > mutation_probability_min) && ...
        (mutate_rand(i) < mutation_probability_max))
      alpha = rand(1); b = 0.5; R=0.1*rand(1);
      T = n_population; t = count;
      temp = (1-t/T)^b;
      beta = 1- R*(temp);
      new_population(i,j) = new_population(i,j) + alpha*beta*...
            (parameter_max(j)-new_population(i,j));
    else
      new_population(i,j) = new_population(i,j) + alpha*beta*...
            (parameter_min(j)-new_population(i,j));
    end
  end
// Creeping Mutation
     alpha = rand(1);
     beta= 0.01;
  for j=1:n_parameter
      if( alpha>=0.5 )
        new_population(i,j) = new_population(i,j) + beta*...
                 (parameter_max(j)-new_population(i,j));
      else
        new_population(i,j) = new_population(i,j) + beta*...
                 (parameter_min(j)-new_population(i,j));
      end
    end
```

Figure 7: Pseudo-code for Mutation operation.

D. Selection of GA

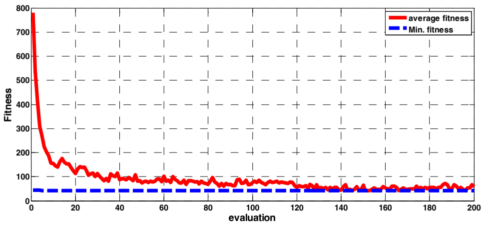
Selection imitates a roulette wheel in determining the population of the next generations, and the scale on the roulette wheel represents the weightings occupied by the population. The weightings are calculated by three steps, including fitness, probability and weighting calculation. The fitness function values of the population processed by crossover and mutation to get the sum. The fitness value divided sum is the selection probability, and the weighting is the summation of probability.

E. Compensated Modeling by GA

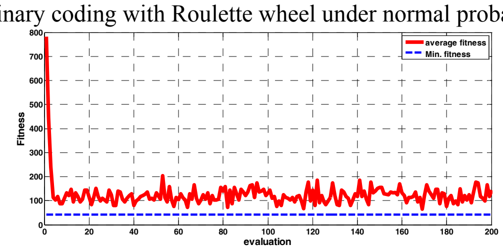
Eq.(1) is calculated by GA algorithm, and furthermore, the masking factor and path loss constant are learning from Taguchi experiments. The test result is shown in TABLE IV, and the table includes population size (N_{ps}), crossover rate (P_{cr}), mutation rate (N_p), size of parent (P_{mr}), path loss constant (n), masking factor (X_{dBm}) and mean square error (MSE). The GA parameters are assigned by operator, and this index presents its performance and learning error. Fig. 8 shows MSE in different conditions.

TABLE IV: Results of GA calculation.

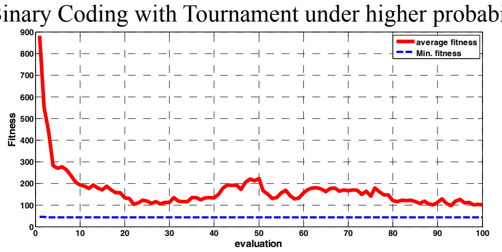
	Run	GA parameters				Shadowing model		
		N_{ps}	P_{cr}	P_{mr}	N_p	n	X_{dBm}	MSE
Binary	1	10	0.8	0.01	100	1.9180	0.15	41.87
	2	5	0.8	0.01	200	1.9303	0.0	41.67
	3	10	0.9	0.05	100	1.9287	-0.06	41.71
	4	5	0.9	0.05	200	1.8870	0.70	42.36
Real	5	10	0.8	0.01	100	1.9297	0.01	41.68
	6	5	0.8	0.01	200	1.9302	-0.00	41.67
	7	10	0.9	0.05	100	1.9292	0.04	41.99
	8	5	0.9	0.05	200	1.9023	0.52	41.87



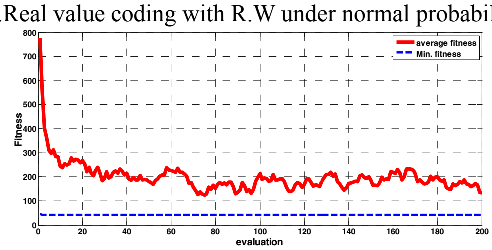
(a).Binary coding with Roulette wheel under normal probability.



(b).Binary Coding with Tournament under higher probability.



(c).Real value coding with R.W under normal probability.



(d).Real value coding with R.W under higher probability.

Figure 8: MSE summation under binary / real value calculation.

The GA and Taguchi method are applied separately in many investigations, but a combination of them applied in DSRC communication design is a new effort. The main considerations of the GA are choosing the proper population size, crossover rate, mutation rate, and the remaining size of the parent to search for optimal solutions most effectively. The MSI includes about thirty experiments, and the average error is only about 1 dBm. The accuracy of estimating distance is less than 4.6 meters. The experiment result shows the applicability of compensated modeling, and the result can calibrate model parameters.

V. CONCLUSION

Taguchi method based on the use of orthogonal arrays was used successfully to determine the optimal conditions necessary for DSRC communication, greatly increasing the availability with optimal parameters in transmitting and receiving packets. Using conventional strategies this would have required an experiment containing 81 separate reactions. However, using the Taguchi method optimization was achieved using just nine reactions. In addition to optimizing product yield, the Taguchi method was used to examine the effects of specific components on data transmitting.

The GA search results may deviate greatly from the optimal solution. The powerfulness of the Taguchi experiments is that they help locate the best GA parameters that give a search result that is closest to the optimal solution and that are the least insensitive to the randomness of the search in this paper. These results may serve as benchmarks of parameters design for future DSRC channel communication.

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