A Ground-Above Security System Classification Algorithm Based on SAA Communication Method

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Abstract:

In sensor network based systems, localization of alarms, communication, environmental compliance and costs are important difficulties which pose an obstacle to find a place in market. In order to eliminate these difficulties, several solutions were produced for years such as Stand Alone Architecture called SAA which is an alternative sensor network data transmission method. In SAA, data transmission is provided by consciously power consuming in nodes and analyzing the data in gateways. However, data transmission was only in one-way direction and environmental compatibility was not a supported feature in SAA. In this study, a classification algorithm for a ground-above security system based on SAA communication method was provided. In order to implement the relevant property; gateway for upgraded SAA nodes, alarm detection/localization algorithms and other necessary supervisory control blocks are designed and successfully simulated.

Keywords: Seismic sensor ; sensor network ; fpga ; footstep detection ; data transmission on current consumption

1. Introduction

In recent years, control systems and the duties of the operators have changed dramatically. Operators of control system activities have changed from manual to automatic usage because of the complexity of systems and cost reduction strategies [1]. These types of systems have spread by the help of supervisory control and sensor network theories. The theory of supervisory control was introduced by Ramadge and Wonham supplies strong frame for the control of discrete event systems [2]. As it mentioned in the article [3], “Supervisory control systems are computers, controllers, instruments; actuators, networks and interfaces that manage the control of automated industrial processes and allow analysis of those systems through data collection”. Also, supervisory control systems and components are used in all types of industries, for example; food processing, security processes of facility and electrical distribution systems [4]. A typical supervisory control system consists of discrete event system, supervisor whose major rule is to make sure that no forbidden state will be reached, sensors and control behaviors as inputs to discrete event systems [5]. Another technology that reduces operator tasks is called sensor networks which offer the ability to display physical events in the real world [6]. According to the article [7], “A sensor network is a distributed collection of nodes which are resource constrained and capable of operating with minimal user attendance”. In these types of systems, production costs, communications infrastructure, environmental variables, methods of achieving knowledge of the action position are important parameters.

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GSM and other wireless communication technologies are popular on these days for transmitting data from one point to another because of the production costs of communication wires [8,9,10]. However, depending on the usage scenario, in some cases wireless systems cloud be more expensive than wired systems. Another important parameter on these type of systems is localization of the event, on which several studies have been done [11,12,13,14,15]. Sensor nodes are usually positioned in the environment and send the alarm report to a central gateway. However, it is essential to know from where the report is sent. Equipping nodes with GPS could generate a solution but power consumption will increase and production of a node would be costly [16]. Acoustic ranging technique could be a solution on localization but using RF signal strength measurements does not produce appropriate solutions [17]. In addition to these difficulties, due to environmental effects, it is necessary to make changes on the nodes hardware. For example, seismic sensors performance are changing on different type of ground and environments, therefore changing the amplification gain produce more successful classification and detection results [18].

The aim of this study is improving the SAA methods adaptation on environmental changes by adding supervisory control features at sensor nodes and gateway architectures also again fully with analog circuits. In this study, adaptation is provided by controlling the sensor node amplifiers gain values automatically from gateway because the sensor nodes can operate better on different environments with different amplifier gain value. Also, to be able to change the sensor node amplifiers gain value, an analog circuit block which could be easily controlled by dc voltage level is being added in to SAA based sensor nodes. Moreover, a specific gateway is being designed on a FPGA simulation environment to read the total current consumption of nodes, to detect alarms, to classify alarms and to control the gain value of sensor nodes adaptively.

2. Materials and Methods

2.1. SAA Method Description

SAA (Stand Alone Architecture) is an alarm data transmission method which based on analysis and control of consciously consumed power at sensor nodes in alarm situations [18]. SAA data transmission method could be used in sensor network systems in which sensor nodes are powered from a single point supply in parallel. SAA method is also designed to eliminate controller and accordingly programming necessity on nodes, to reduce node manufacturing, installation costs and to provide easy installation on sensor network based systems. However, SAA based systems were unable to adapt to environmental changes because of one-way data transmission.

As it is seen in Figure-1, all nodes are connected in parallel to dc supply and current consumption behavior model of nodes contains only 2 conditions such as; normal mode behavior called RN and alarm mode behavior called RA [18]. RT Load resistors are also placed in sensor nodes in SAA based network systems. If an alarm situation occurs in a sensor node, current consumption behavior of this node turns to RA mode in which dc supply shortens to ground with a specific resistor. This specific resistor value for RA mode is all same in each node. However, supply voltage is decreasing along the power line so the power consumption values in alarm condition differ for each node according to the place of nodes in power line. In normal mode, sensors are consuming very low and stable powers with respect to alarm mode so alarm detection and classification could be easily done at gateway control blocks by reading the output current of dc supply instantly.

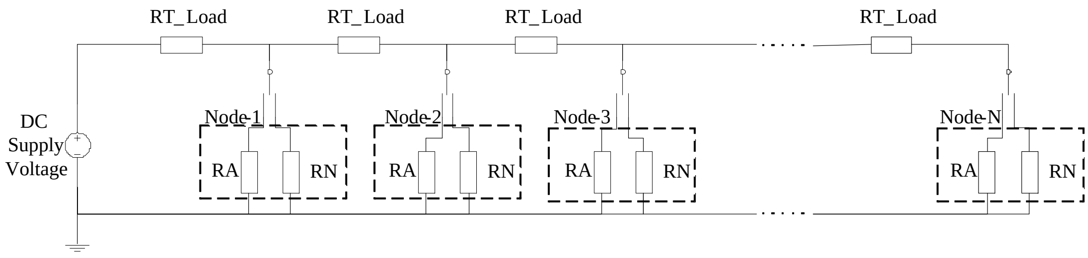

Figure-1 Current consumption model of the SAA based sensor nodes system

In the previous version of SAA methodology, there is only two core exist in power cable such as 12 VDC and ground. Therefore, only one-way communication is provided in SAA methodology. As it can be seen in Figure-2, in this study, an additional core is being added in to power cable called DAC which represent the gain values of amplifier circuits in SAA based sensor nodes. So, the optimum amplifier circuit gain value could be obtained in different soil type which geophone sensors are connected. In addition, effects of the weather conditions on soil could be easily identified and gain calibration could be automatically done in system which is designed in this study.

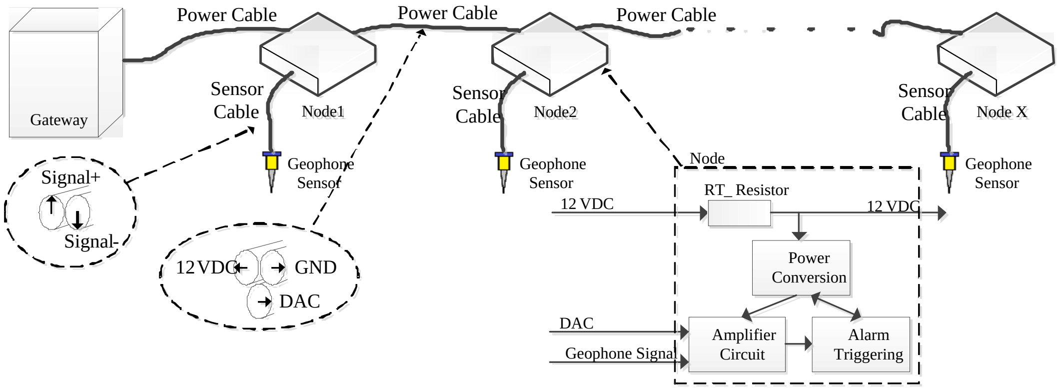

Figure-2 Modified SAA Gateway, Node and Sensor Cabling

2.2. Hardware Modifications on SAA based Nodes

Optimal amplifier gain value of seismic sensor called geophone is varying depending on environmental conditions [18]. For example, appropriate gain level in dry soil is lower than the moist soil. So, detection and classification performances of SAA nodes will be changed dramatically in different type of soil if a fixed gain value is used in sensor nodes. Therefore, in this study, gain values of SAA nodes are controlled by gateway to fix this problem with using digital voltage dividers between sensor output and ADC input.

2.3. Gateway Architecture and Control Algorithms

In the previous version of SAA methodology, there is not any gateway or gateway control algorithms designed. Studies mentioned below are not modifications; they are completely designed from zero point. Main tasks of the SAA based security systems gateway designed in this study are; finding the number of connected nodes, alarm detection, identifying node which is the source of alarms, measuring the swinging on current consumption, calibrating the gain value of nodes according to environmental conditions automatically. Control blocks are named in this paper such as; load profile control block, node number at system measuring block, current swing measuring control block, alarm detection control block, gain calibration control block, alarm classification control block, specific node current transfer control block and clock block. Connections between gateway blocks could be easily seen in Figure-3.

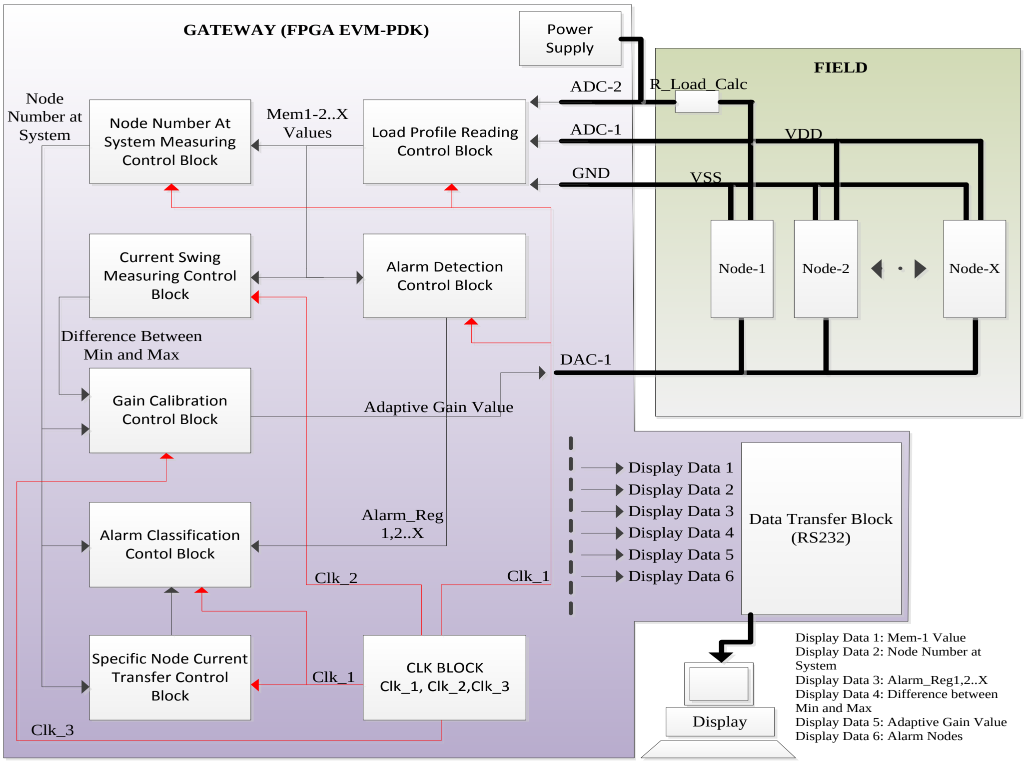

Figure-3 Gateway architecture and control blocks

As shown in Figure-3, all SAA nodes are connected parallel together and the total current consumption of nodes are measured by calculating the difference of ADC-1 and ADC-2 channel. Main task of load profile reading control block is keeping the last 50 current values in its memory which called RM_i is refreshed with each clock pulse.

$$i = \{1, 2, \ldots, 50\} \tag{1}$$

$$t_{clk1} = \{0_{ms}, 20_{ms}, 40_{ms}, \ldots, \infty\} \tag{2}$$

$$\forall\, t_{clk1}, \qquad \forall\, i - \{i = 1\}; \tag{3}$$

$$RM_i\left(t_{clk_1}\right) = RM_{i-1}(t_{clk1} - 1) \tag{4}$$

$$RM_1(t_{clk1}) = ADC(t_{clk1}) \tag{5}$$

As shown in Figure-3, the memory produced by load profile reading control block is connected to another important block named node number at system measuring control block whose main task is continuously calculating the number of nodes connected to the gateway. If a new node added to the system or power cable between nodes is being cut, this control block would detect the situation instantly. A limit value is defined for currents called AC to stop measurements in alarm conditions so node number calculations are being done in only normal modes. In equations, to represent the average total current value AverageRN term is defined. To round fractional results correctly, a term called HalfRM is being used and the node number at system is represented with term called $NodeNmbr_{(t_{clk1})}$.

$$if(x) = \begin{cases} 1, & x\ is\ true, \\ 0, & x\ is\ false, \end{cases} \tag{6}$$

$$NodeNmbr(t_{clk1}) = \ if\big(AC > RM_{\forall i}(t_{clk1})\big) * \frac{HalfRM + \sum_{i=1}^{i=50} RM_i(t_{clk1})}{AverageRN} + \tag{7}$$

$$if(AC < RM_{\forall i}(t_{clk1})) * NodeNmbr(t_{clk1} - 1) \tag{8}$$

Another important control block named current swing measuring control block's main task is measuring the amplitude of the swing on total current consumption. Maximum and minimum values are measured with different clock pulse which is 50 times slower than clk1 called clk2. Also, the maximum and minimum differences are stored in a different memory cell which could keep last 4 differences. The output of this control block is called $AverageSwing\ (t_{clk2})$ which represents the amplitude of the swinging on total current consumption.

$$t_{clk2} = \{0_s\,, 1_s\,, 2_s\,, .\,.\,, \infty\} \tag{9}$$

$$\forall t_{clk2}\,, \forall i\,; \tag{10}$$

$$MaxRM(t_{clk2}) = if\big(RM_i(t_{clk2}) > RM_{i-1}(t_{clk2})\big) * (RM_i(t_{clk2})) \tag{11}$$

$$MinRM(t_{clk2}) = if\big(RM_i(t_{clk2}) < RM_{i-1}(t_{clk2})\big) * (RM_i(t_{clk2})) \tag{12}$$

$$Swg(t_{clk2}) = MaxRM(t_{clk2}) - MinRM(t_{clk2}) \tag{13}$$

$$AverageSwing\ (t_{clk2}) = if\big(AC > RM_{\forall i}(t_{clk2})\big) \tag{14}$$

$$* \frac{Swg(t_{clk2}) + Swg(t_{clk2} - 1) + Swg(t_{clk2} - 2) + Swg(t_{clk2} - 3)}{4} \tag{15}$$

$$+ if\big(AC < RM_{\forall i}(t_{clk2})\big) * AverageSwing(t_{clk2} - 1) \tag{16}$$

Main purpose of another control block called alarm detection control block is to keep and write signals only over a certain threshold (AC) to another memory cells. These memory cells are called $AR_j(t_{clk1})$. If last 15 $RM_i(t_{clk1})$ values are under the AC threshold, all $AR_j(t_{clk1})$ values are being set to zero, so detection of different alarms has facilitated.

$$j = \{1\,, 2\,, .\,.\,, 15\} \tag{17}$$

$$\forall t_{clk1}\,, \forall j - \{j = 1\}; \tag{18}$$

$$AR_1(t_{clk1}) = \Big(if\big(AC < RM_1(t_{clk1})\big) * RM_1(t_{clk1})\Big) * \ if(AC < \ RM_{\forall j}(t_{clk1})) \tag{19}$$

$$AR_j(t_{clk1}) = \Big(if\big(AC < RM_1(t_{clk1})\big) * AR_{j-1}(t_{clk1} - 1) + if\big(AC > \ RM_1(t_{clk1})\big) * AR_j(t_{clk1})\Big) \tag{20}$$

$$* if(AC < RM_{\forall j}(t_{clk1})) \tag{21}$$

To classify separated alarm signals ($AR_j(t_{clk1})$; possible current values of alarm nodes according to node number at system are being required. Alarm current of a node is dependent to the number of nodes in the whole system. The following matrix called $CLFull_{x,y}$ contains the limit values of alarm currents for each node. Topmost horizantal column represents the first nodes higher alarm current value and the topleft vertical column represents the node numbers in whole system starting from 3. These values are taken from a model which is generated in the study [18]. All current values in this study are being set with the same unit (100uA). Term called $CL_y(t_{clk1})$ is carrying the appropriate column values to the next block depending on the number of node in the system.

$$x = \{1, 2, .., 8\}\ ;\ y = \{1, 2, .., 11\} \tag{22}$$

$$CLFull_{x,y} = \begin{Bmatrix} 591 & 596 & 600 & 601 & 607 & 610 & 616 & 617 \\ 565 & 569 & 573 & 576 & 579 & 583 & 587 & 590 \\ 541 & 544 & 547 & 550 & 554 & 556 & 560 & 563 \\ 523 & 522 & 525 & 527 & 530 & 532 & 536 & 539 \\ 000 & 506 & 504 & 506 & 508 & 511 & 513 & 517 \\ 000 & 000 & 488 & 487 & 489 & 492 & 494 & 497 \\ 000 & 000 & 000 & 474 & 472 & 474 & 476 & 478 \\ 000 & 000 & 000 & 000 & 459 & 458 & 459 & 462 \\ 000 & 000 & 000 & 000 & 000 & 445 & 444 & 447 \\ 000 & 000 & 000 & 000 & 000 & 000 & 434 & 432 \\ 000 & 000 & 000 & 000 & 000 & 000 & 000 & 422 \end{Bmatrix} \tag{23}$$

$$CL_y(t_{clk1}) = if(NodeNmbr(t_{clk1}) = 3) * CLFull_{1,y} + if(NodeNmbr(t_{clk1}) = 4) * CLFull_{2,y} \tag{24}$$

$$+ if(NodeNmbr(t_{clk1}) = 5) * CLFull_{3,y} + if(NodeNmbr(t_{clk1}) = 6) * CLFull_{4,y} \tag{25}$$

$$+ if(NodeNmbr(t_{clk1}) = 7) * CLFull_{5,y} + if(NodeNmbr(t_{clk1}) = 8) * CLFull_{6,y} \tag{26}$$

$$+ if(NodeNmbr(t_{clk1}) = 9) * CLFull_{7,y} + if(NodeNmbr(t_{clk1}) = 10) * CLFull_{8,y} \tag{27}$$

Another important control block is called alarm classification control block which determines alarm nodes by doing calculations on alarm values $AR_j(t_{clk1})$. First, the size of alarm memory ($AlarmRegisterSize(t_{clk1})$) is being measured and then average alarm current ($AverageAlarmCurrent\ (t_{clk1})$) value is calculated by dividing the sum of alarm values to the size of alarm memory. In the final stage, alarm node is being detected by comparing average alarm value with $CLFull_{1,y}$ values which are produced in specific node current transfer control block.

$$i = \{1, 2, .., 15\} \tag{28}$$

$$AlarmRegisterSize(t_{clk1}) = \sum_{i=1}^{i=15} if\ (AR_i(t_{clk1}) > 0) \tag{29}$$

$$AverageAlarmCurrent\ (t_{clk1}) = \frac{\sum_{i=1}^{i=15} AR_i(t_{clk1})}{AverageRegisterSize(t_{clk1})} \tag{30}$$

$$AlarmNode(t_{clk1}) = \sum_{i=1}^{i=11} if\big(CL_i(t_{clk1}) > AverageAlarmCurrent\ (t_{clk1}) > CL_{i+1}(t_{clk1})\big) * i \tag{31}$$

The most important and the final control block is called gain calibration control block. Main purpose of this control block is changing the gain value of nodes by producing 5 different DC voltage level. Equivalent DAC register value called $DACGainValue\ (t_{clk3})$ of these voltage levels are such as; 65500, 60041, 54583, 49125 and 43666 in order.

$$DACGainValue\ (t_{clk3}) = if(1 < AverageSwing\ (t_{clk2}) \leq 5) * 65500 \quad (32)$$

$$+ if(5 < AverageSwing\ (t_{clk2}) \leq 10) * 60041 + if(10 < AverageSwing\ (t_{clk2}) \leq 15) * 54583 \quad (33)$$

$$+ if(15 < AverageSwing\ (t_{clk2}) \leq 20) * 49125 + if(20 < AverageSwing\ (t_{clk2}) \leq 50) * 43666 \quad (34)$$

$$+ if(AverageSwing\ (t_{clk2}) = 0) * 54583 + if\big(50 < AverageSwing\ (t_{clk2})\big) * 54583 \quad (35)$$

3. Results

Gateway simulations are executed to verify the related control blocks desired functional behaviors. In this section, two different type simulations were performed. First one is called normal mode simulations and the other one is called alarm mode simulations.

3.1. Normal Mode Simulation Results

First of all, normal mode simulations are executed with different swinging levels and different node number at system on Xilinx simulation platforms. As can be seen from the Figure-4, in every 4 seconds, swinging level is being changed in the input data. Also, in every 12 seconds, node number connected to gateway is being increased. Expected result on node number calculation of this simulation is; node number should be increased by 1 in every 600 samples. In every 4 second, noise level of input data is being changed with 3 different noise level as can be seen from Figure-4. Swing-3 represents the highest noise level on input data and swing-1 represents the lowest noise level as well.

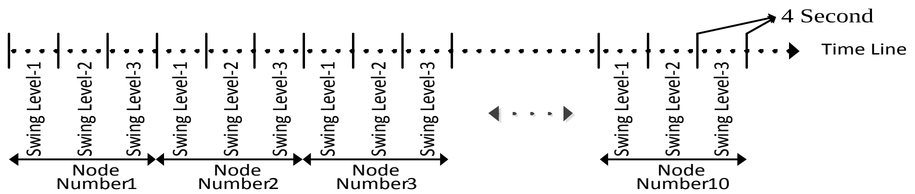

Figure-4 Normal mode simulation map

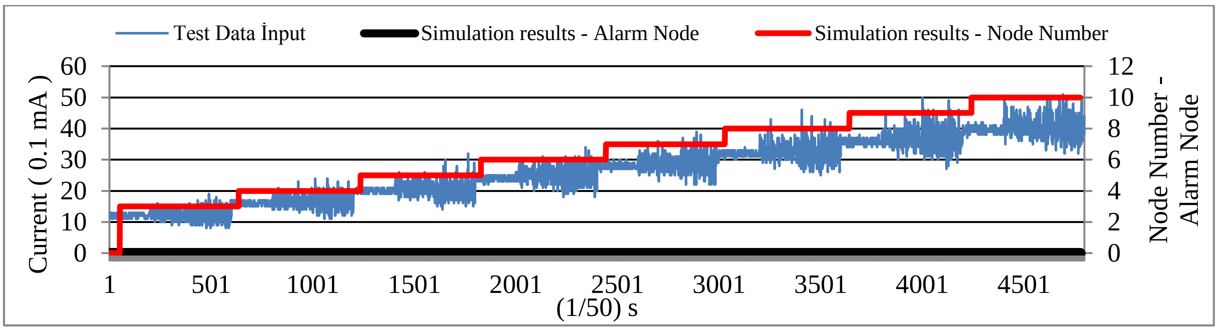

Figure-5 Normal Mode Noise Test - Node Number and Alarm Node Simulation Results

As seen in Figure-5, node number connected to gateway is calculated correctly by the gateway control blocks. Also in Figure-6, average swinging measurements and DAC gain value calibrations are acting in a way as expected as mentioned above.

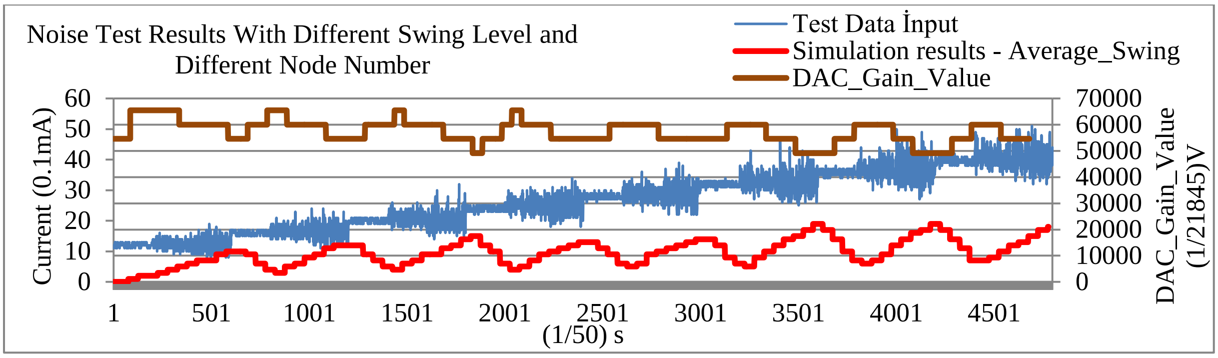

Figure-6 Noise Test – Average Swing and DAC Value Simulation Results

3.2. Alarm Mode Simulation Results

Another important simulation is executed on alarm mode with different node numbers, different swinging level and different alarm node. As can be seen from the Figure-7, in every 2 seconds different node is producing alarm in an order and in every 20 seconds swinging level is being changed.

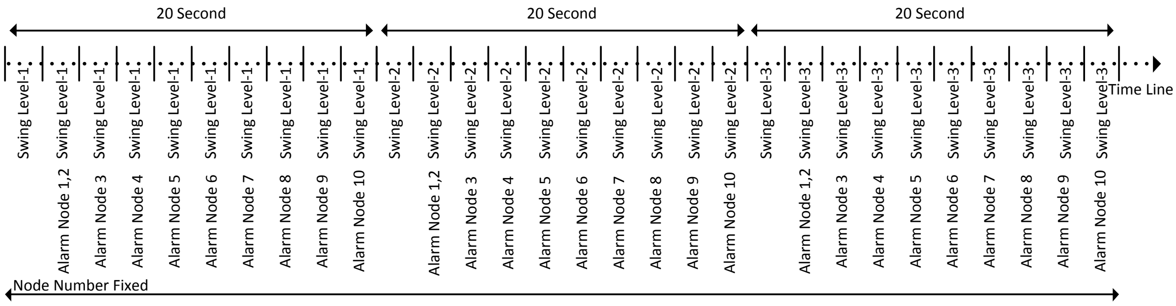

Figure-7 Alarm mode simulation map

Before evaluating the simulation results, performance criteria's should be defined. The relevant simulation performance criteria's and descriptions are mentioned in Table-1.

Table-1 Alarm simulation performance criteria table

Performance Criteria	Definitions
True Detection (TD,TC)	Input has alarm signal, correct detection/classification is being produced by alg.
Miss Detection (MD, MC)	Input has alarm signal correct detection/classification is not being produced by alg.
False Detection (FD, FC)	Input has no alarm signal false detection/classification is being produced by alg.
Corr. Rej. For Detection/Class.	Input does not have alarm signal, any detection/classification is produced by alg.

Correct rejection ratio could be accepted %100 in both detection and classification when there is not any intruder. So, the probabilities of true, false and missed detections/classifications are calculated by the formulas in the Figure-8.

Alarm Signal

True Detection Rate = Correctly Detected Signal / Number of İntruder Movement	False Detection Rate = İncorrectly Detected Signal / Number of İntruder Movement	Missed Detection Rate = 1-(True Detection Rate)-(False Detection Rate)

Figure-8 Detection rate calculation criteria

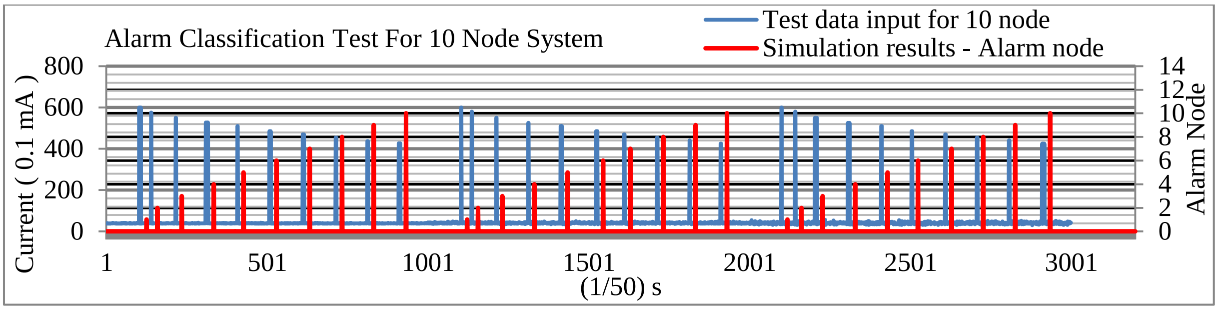

Figure-9 Alarm Mode – Alarm node simulation results for 10-Nodes system

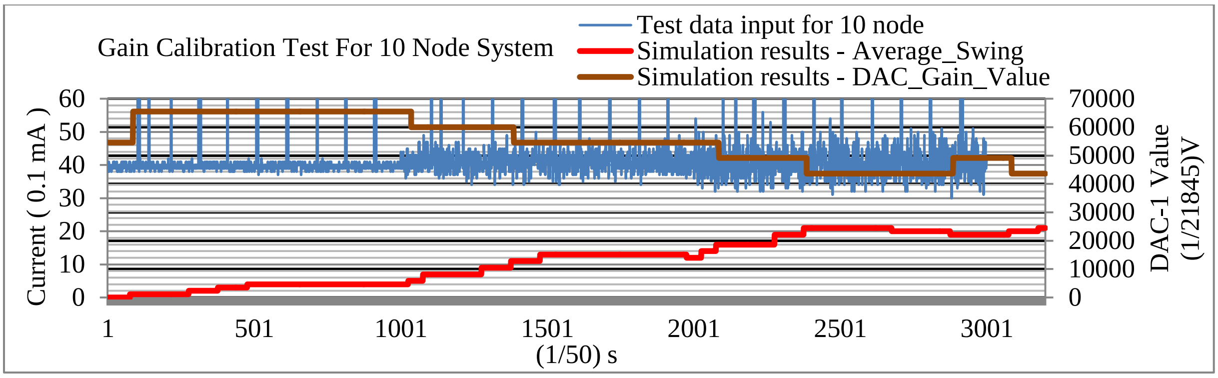

Figure-10 Alarm Mode – Average swing and DAC value simulation results for 10-Nodes system

Figure-9 and Figure-10 shows only the alarm mode simulation results for 10-node system. After analyzing the normal mode and alarm mode simulation results, it can easily be seen that the corresponding algorithm is compatible with the model produced in the study [18].

5. Conclusions

As it seen in the result section; node number in the system, detection of an intrusion, alarm localization, gain/noise calibration can be successfully implemented with the gateway algorithms. SAA nodes are designed with fully analog components so this property generate some advantages such as; easy and quick supply process, easy production, simple quality control after production, quick installations, low service effort, low component addiction, simple PCB requirements, low node costs, short BOM lists and low operation costs. Also with this study, compatibility of environmental conditions successfully developed and integrated to the SAA based ground above security system.

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