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Navigation Control of Agent Automobiles Using Wireless Sensor Network

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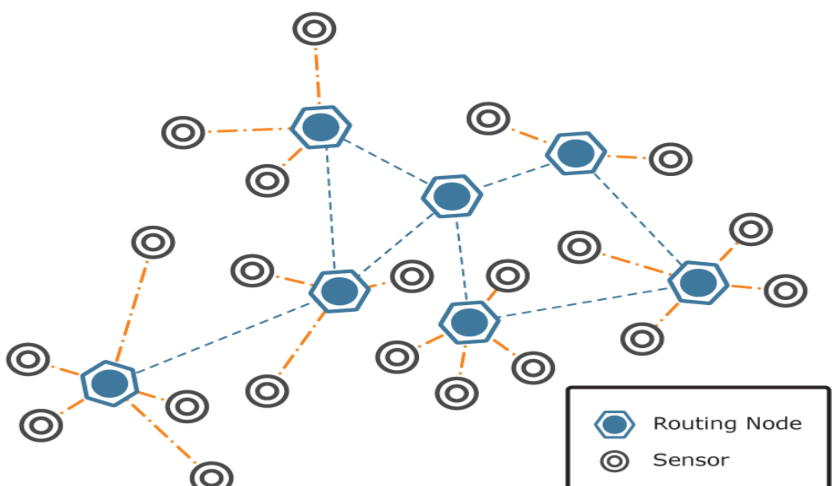
Introduction

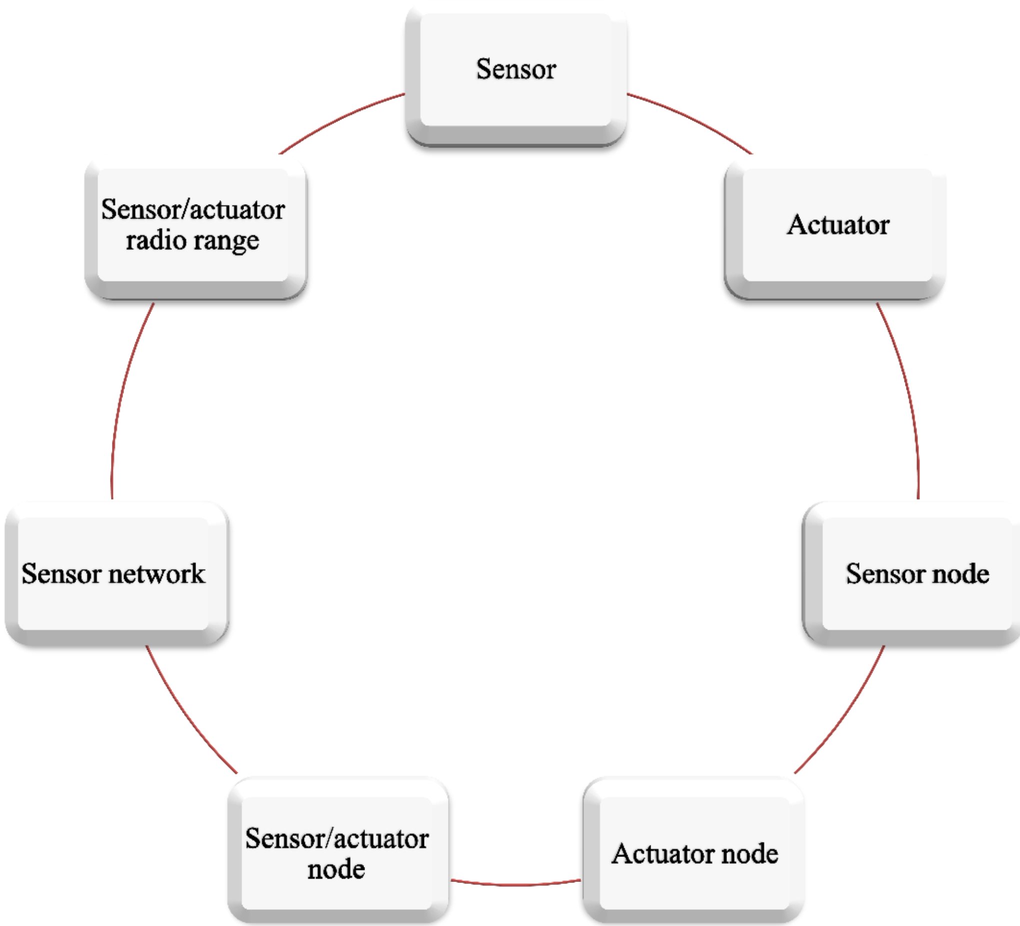
Wireless communication is one of the main fundamentals of wireless sensor networks that are considered by researchers in the last decades. Furthermore, fuzzy logic is a useful tool to design and control the complex and unpredicted systems. A smart fire system is proposed in this thesis to monitor, control, and report fire events. This system uses several fuzzy controllers to conduct data routing, make appropriate decision, event detection, etc. It is worth to noting that navigation control of agent automobiles is one of the main elements of this system.

Wireless Sensor Networks

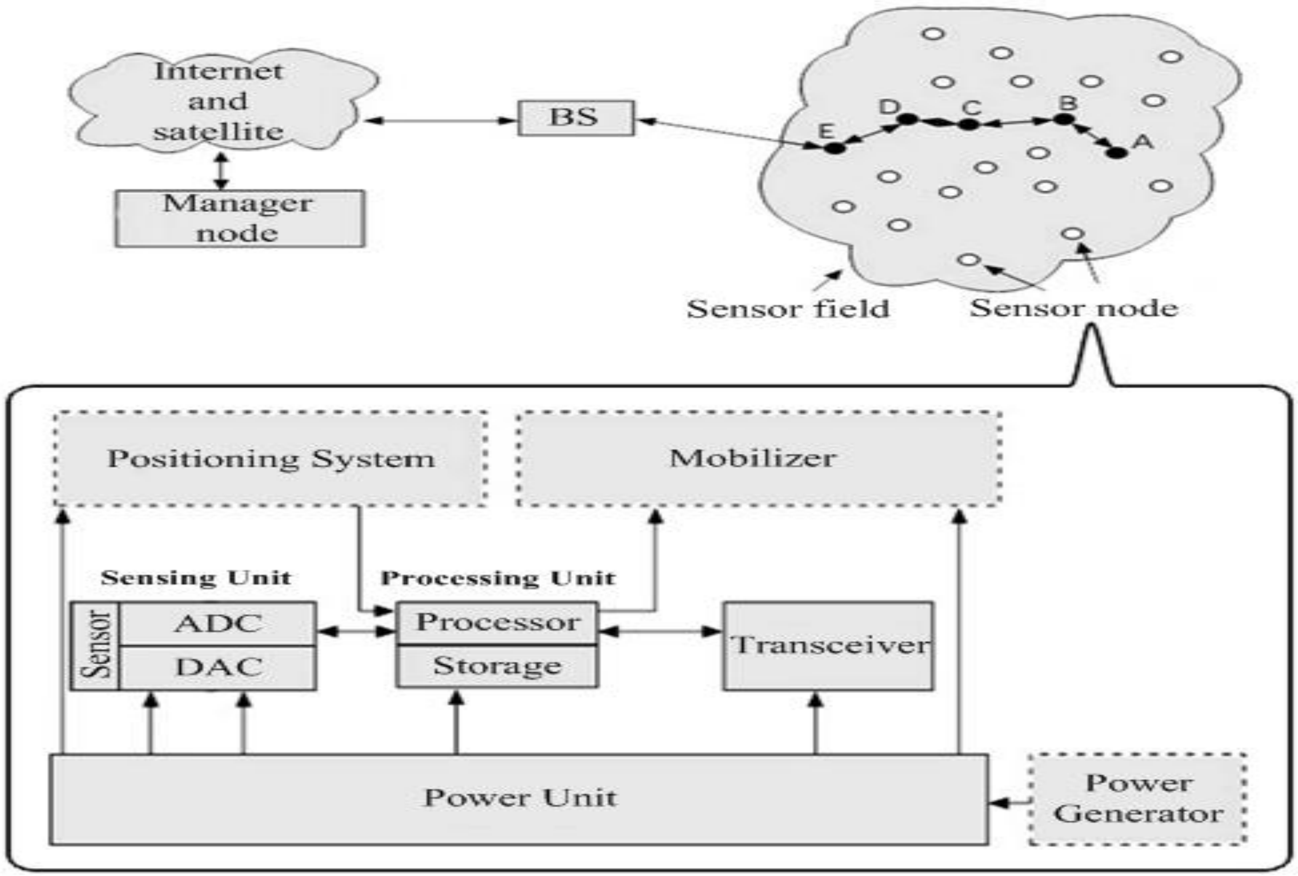
Wireless sensor networks are composed of low-energy, low-cost, large-scale sensor nodes. The nodes can communicate with each other without any initial structure. They have some constraints such as processing power, memory storage, and energy power. These constraints cause to some of the big challenges in these networks that should be attended by researchers.



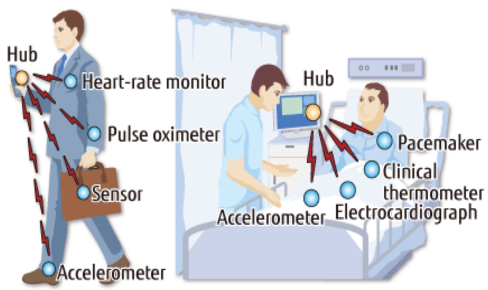
Structure of Sensor Network/Wireless Actuator

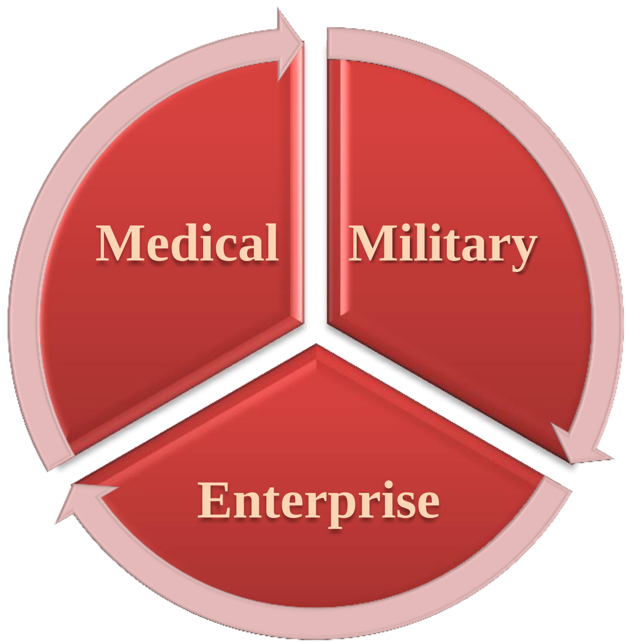


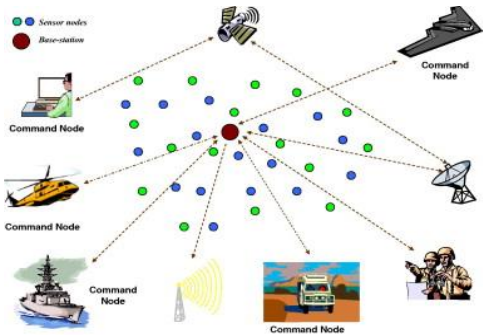
Structure of a Sensor Node Inside a Sensor Network

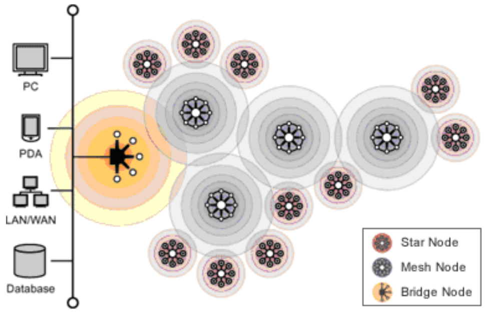


Applications of Wireless Sensor Networks









Classic Logic

In classic logic, an statement is true or false. True statement is indicated by $T(P)=1$ and false statement is indicated by $T(P)=0$. Membership degree of element x in set A with universe of discourse U is represented by $\mu_A(x)$ as the below:

$$\mu_A(x)=\begin{cases} 1 & \text{if } x\in A \\ 0 & \text{if } x\notin A \end{cases}$$

Example:

$U=\{1, 2, 3, 4, 5\}$, $A=\{1, 3, 4\}$

$\mu_A(1)=1$ and $\mu_A(5)=0$

Fuzzy Logic

In this logic, like classic logic, membership degree of elements is represented by $\mu_A(x)$ where x is an element of set A and μ is a membership function that determines belongingness degree of x to A.

Example:

U={1, 2, 3, 4, 5}

A={(0.4/1), (1.0/2), (0.5/3), (0.0/4), (0.0/5)}

Steps of Fuzzy Sets

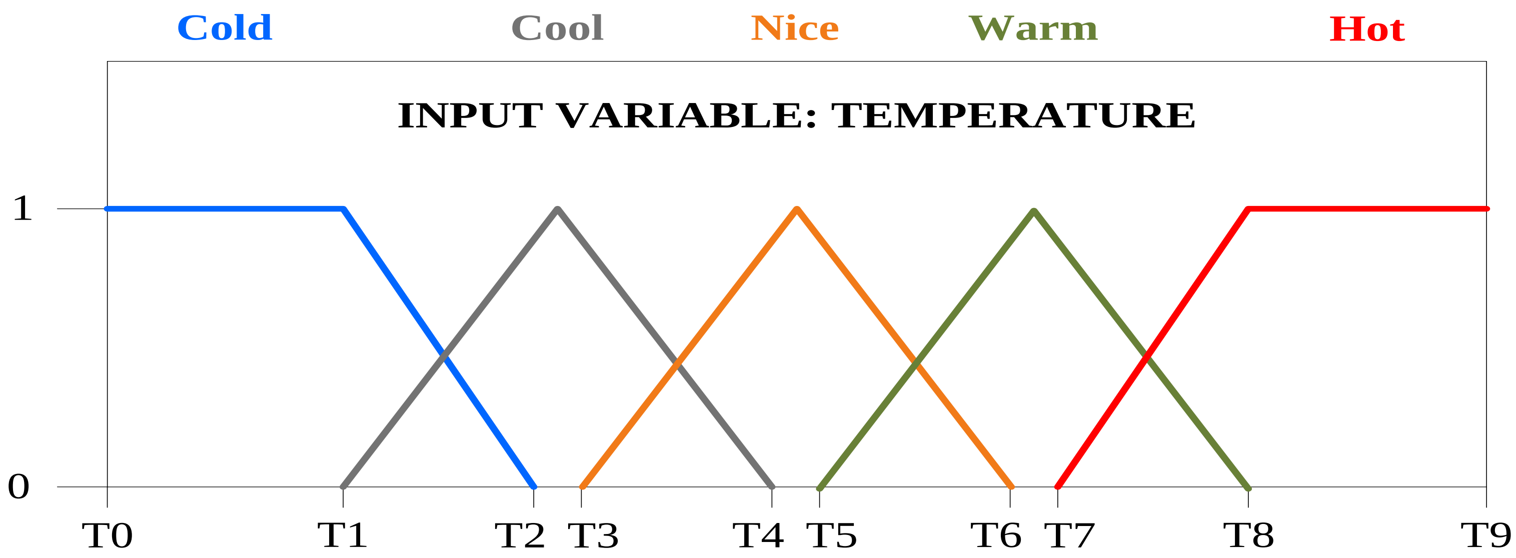
Specify the minimum and maximum values of the universe of discourse

Define linguistic terms

Split the minimum and maximum values to several parts

Determine membership functions

An Example of Linguistic Terms in Fuzzy Logic



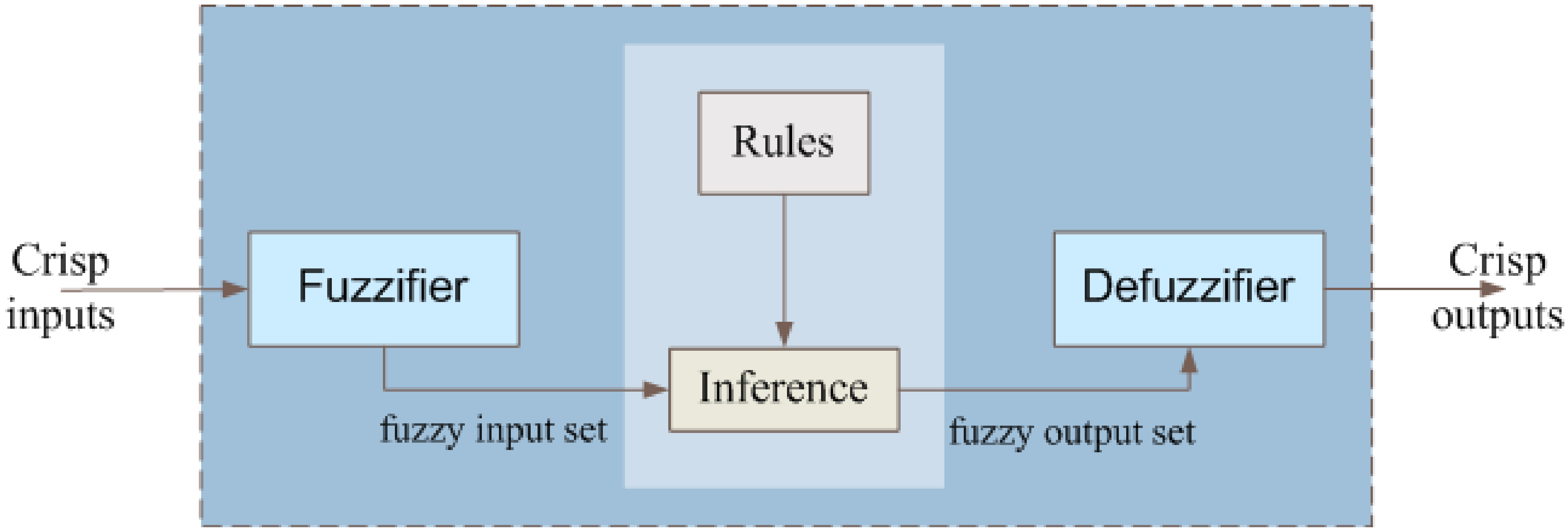
U={-40, -10, 5, 20, 30, 50}

Warm={(0.0/-40), (0.0/-10), (0.0/5), (0.4/20), (1.0/30), (0.5/50)}

Some of the Fuzzy Rules in a Detection System of Automobile Speed

Input parameters		Output parameter
Weight (ton)	**Brake line (meter)**	**Speed (km/h)**
Very light	Very short	Very low
Light	Short	Low
Normal	Moderate	Medium
Heavy	Long	High
Very heavy	Too long	Very high

Fuzzy Logic System (FLS)



The Proposed Smart Fire System

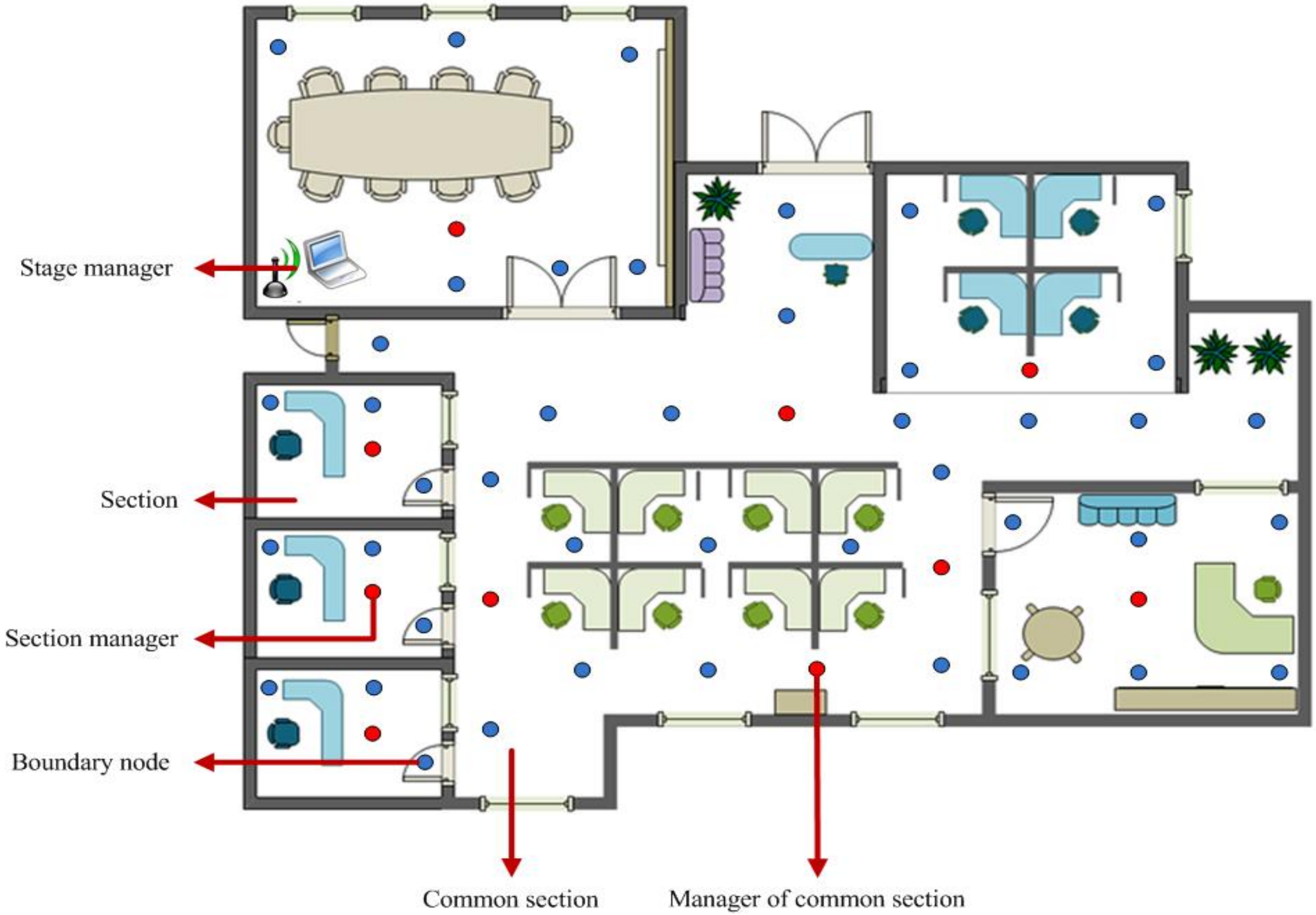
Elements of the proposed smart fire system to monitor, control, and report fire events based on fuzzy decision making are listed as the followings:

- System architecture
  - The considered environments
    - Indoor environment
    - Outdoor environment
    - Data transmission methods in the environments
  - Network identifier (NI)
- Packet format
- 3D fuzzy routing
- Determining the state of sensor nodes
- Data aggregation methods
- Event detection
- Fire fighting operations
- Determining the fault probability of sensor nodes

Indoor Environment

- ✓ This environment can be composed of multiple stages.
- ✓ Every stage can be divided to several parts denoted by section.
- ✓ Common spaces between sections at every stage (e.g., hallway) is denoted by common section.
- ✓ 3D static fuzzy routing is used for data transmissions into common sections.
- ✓ Every section includes various boundary nodes to communicate data packets between the manager of sections and the nodes of common sections.
- ✓ Every stage has a stage manager that makes relation between the manager of common sections and the environment manager.
- ✓ The managers of common sections communicate with each other and also with the environment manager via the wireless or wired communications.

Schematic of a Stage in the Indoor Environment



Outdoor Environment

- ✓ Every outdoor environment is composed of various parts, denoted by section. Every section has a manager.
- ✓ Common paths between several sections at each level is denoted by interface way that has a unique identifier.
- ✓ Data transmissions between the nodes of interface ways are conducted by 3D fuzzy routing.
- ✓ Initial decision to detect various events and/or perform operations is made by the environment manager.

Data Transmission Process in the Environments

Data transmission process is determined based on a feature namely ‘SendDataType’. This feature is stored in sensor nodes of the section, stage, and environment managers. Nodes of every section transmit all the sensing data to the section manager without any data aggregation mechanism. In contrast, section manager can transmit all of the gathered data or only the data packets aggregated by a fuzzy process to the top-level manager.

Network Identifier (NI)

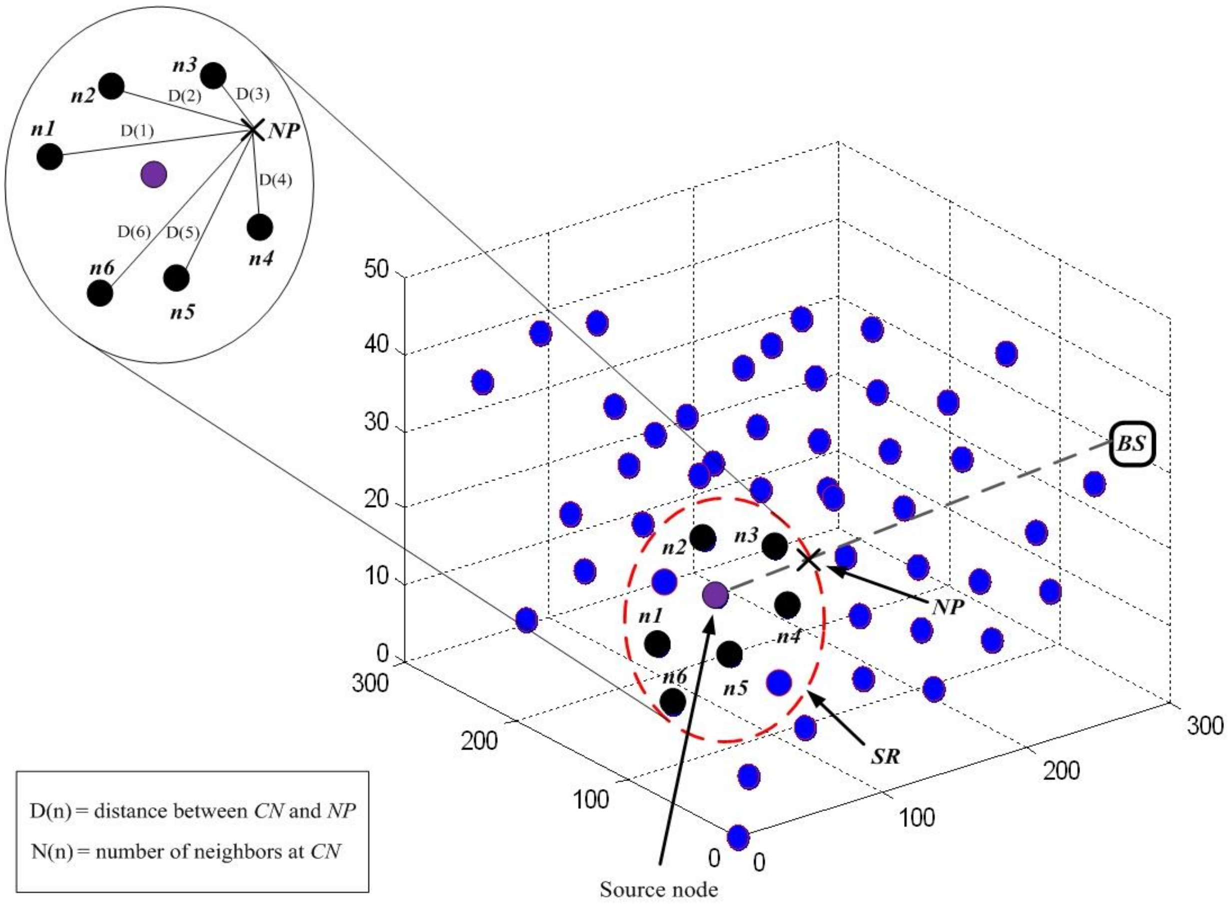
All elements of the system are identified by a network identifier (NI). This identifier is composed of five segments as the below:

- Environment No. or fire department No.
- Section No.
- Stage No. in the indoor environment
- Section No. or common section No.
- Node No.

3D Fuzzy Routing

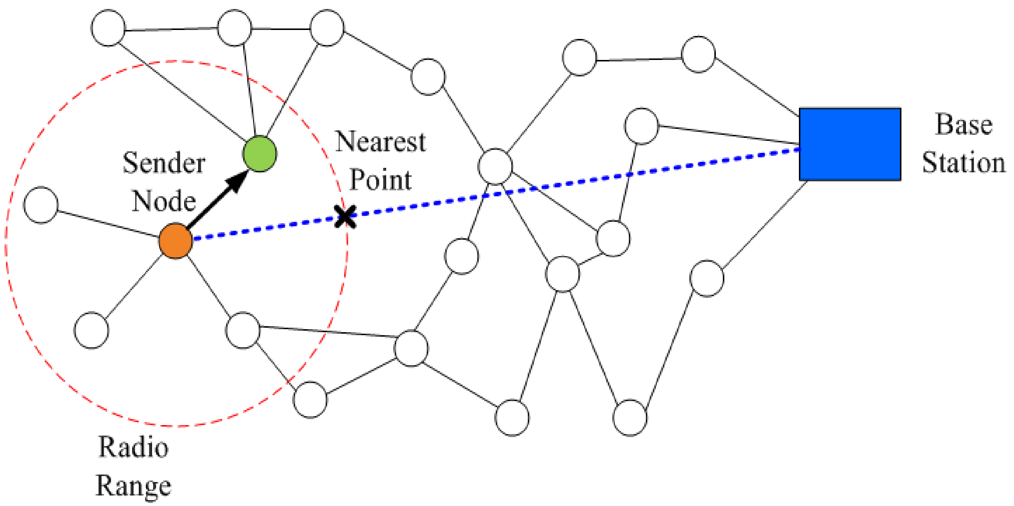
- Static 3D fuzzy routing protocols
  - Static 3D fuzzy routing based on receiving probability (SFRRP)
  - Static 3D fuzzy routing based on traffic probability (SFRTP)
  - Static 3D fuzzy routing based on the receiving and traffic probabilities (SFRRTP)
- Dynamic 3D fuzzy routing protocols
  - Dynamic 3D fuzzy routing based on receiving probability (DFRRP)
  - Dynamic 3D fuzzy routing based on traffic probability (DFRTP)
  - Dynamic 3D fuzzy routing based on the receiving and traffic probabilities (DFRRTP)

To Select an Appropriate Neighbor in 3D Fuzzy Routing



Geographical Coordinates of the Points in 3D Fuzzy Routing

- Geographical coordinates of the base station
  - BS_x : axis x of the base station
  - BS_y : axis y of the base station
  - BS_z : axis z of the base station
- Geographical coordinates of the sender node
  - $Node_x$: axis x of the sender node
  - $Node_y$: axis y of the sender node
  - $Node_z$: axis z of the sender node
- Geographical coordinates of the neighbor node
  - $Neighbor_x$: axis x of the neighbor node
  - $Neighbor_y$: axis y of the neighbor node
  - $Neighbor_z$: axis z of the neighbor node
- Geographical coordinates of the nearest point on the sender node's signal range
  - P_x : axis x of the nearest point
  - P_y : axis y of the nearest point
  - P_z : axis z of the nearest point



Distance Between Sender Node and the Base Station in 3D Fuzzy Routing

$$\begin{cases} V_x = BS_x - Node_x \\ V_y = BS_y - Node_y \\ V_z = BS_z - Node_z \\ magV = \sqrt{V_x^2 + V_y^2 + V_z^2} \end{cases}$$

$$\begin{cases} P_x = Node_x + [(V_x/magV) * R] \\ P_y = Node_y + [(V_y/magV) * R] \\ P_z = Node_z + [(V_z/magV) * R] \end{cases}$$

$$Distance = \sqrt{(P_x - Neighbor_x)^2 + (P_y - Neighbor_y)^2 + (P_z - Neighbor_z)^2}$$

Linguistic Terms of the 3D Fuzzy Routing

Distance	The number of neighbors	The receiving, traffic, and success probabilities
• Very near • Near • Moderate • Away • Far away	• Feeble • Few • Normal • Many • Lots	• Very low • Low • Medium • High • Very high

Fuzzy Decision Making in the 3D Fuzzy Routing

Protocol	Input parameters		Output parameter
	First parameter	Second parameter	
SFRRP	Distance	The number of neighbors	Receiving probability
SFRTP	Distance	The number of neighbors	Traffic probability
SFRRTP	Receiving probability	Traffic probability	Success probability
DFRRP	Distance	The number of neighbors	Receiving probability
DFRTP	Distance	The number of neighbors	Traffic probability
DFRRTP	Receiving probability	Traffic probability	Success probability

Some of the Fuzzy Rules in SFRRP and SFRTP

Input parameters		Output parameters	
Distance	**The number of neighbors**	**Receiving probability in SFRRP**	**Traffic probability in SFRTP**
Away	Many	Low	High
Near	Few	Medium	Low
Very near	Lots	High	High
Far away	Feeble	Very low	High
Moderate	Lots	Medium	High

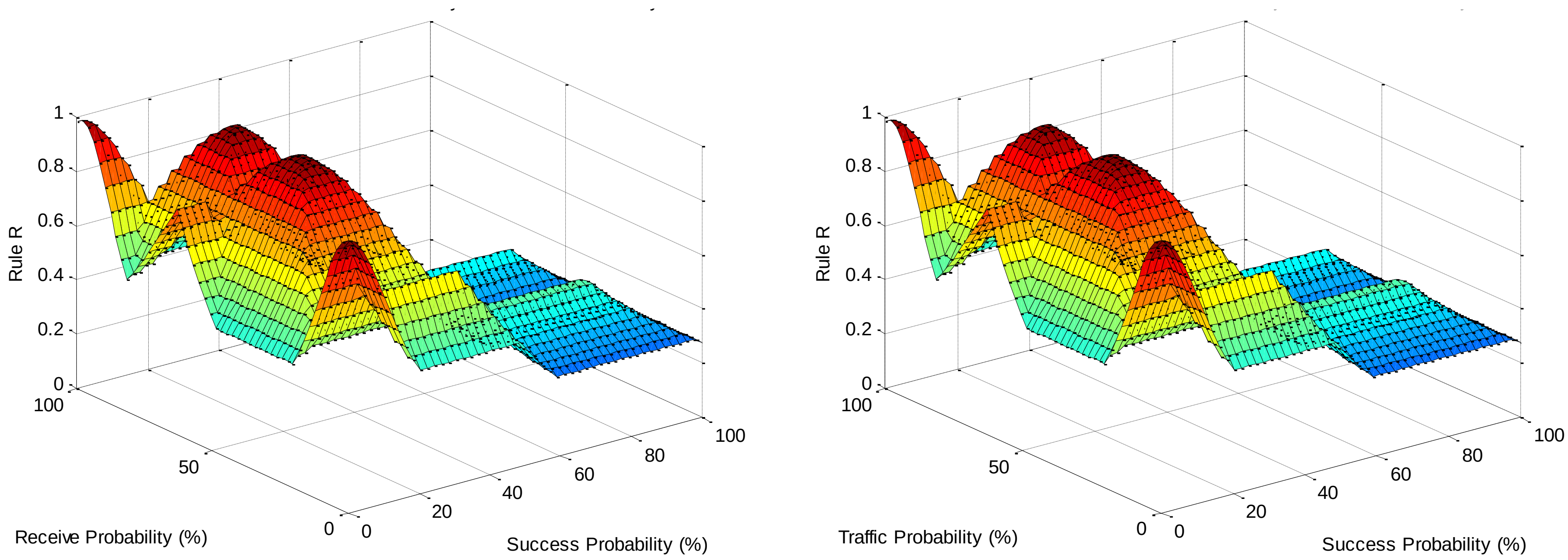
Some of the Values in SFRRP and SFRTP

Node No.	Input parameters		Output parameters	
	Distance	The number of neighbors	Receiving probability in SFRRP	Traffic probability in SFRTP
1	140	5	46.225	53.153
2	120	10	41.572	58.167
3	65	3	48.311	47.668
4	90	7	45.212	52.916
5	15	1	47.962	42.043

Some of the Fuzzy Rules in SFRRTP

Input parameters		Output parameter
Receiving probability	**Traffic probability**	**Success probability**
Very low	Medium	Very low
Low	Medium	Low
Medium	Medium	Low
High	Low	Medium
Very high	Low	Very high

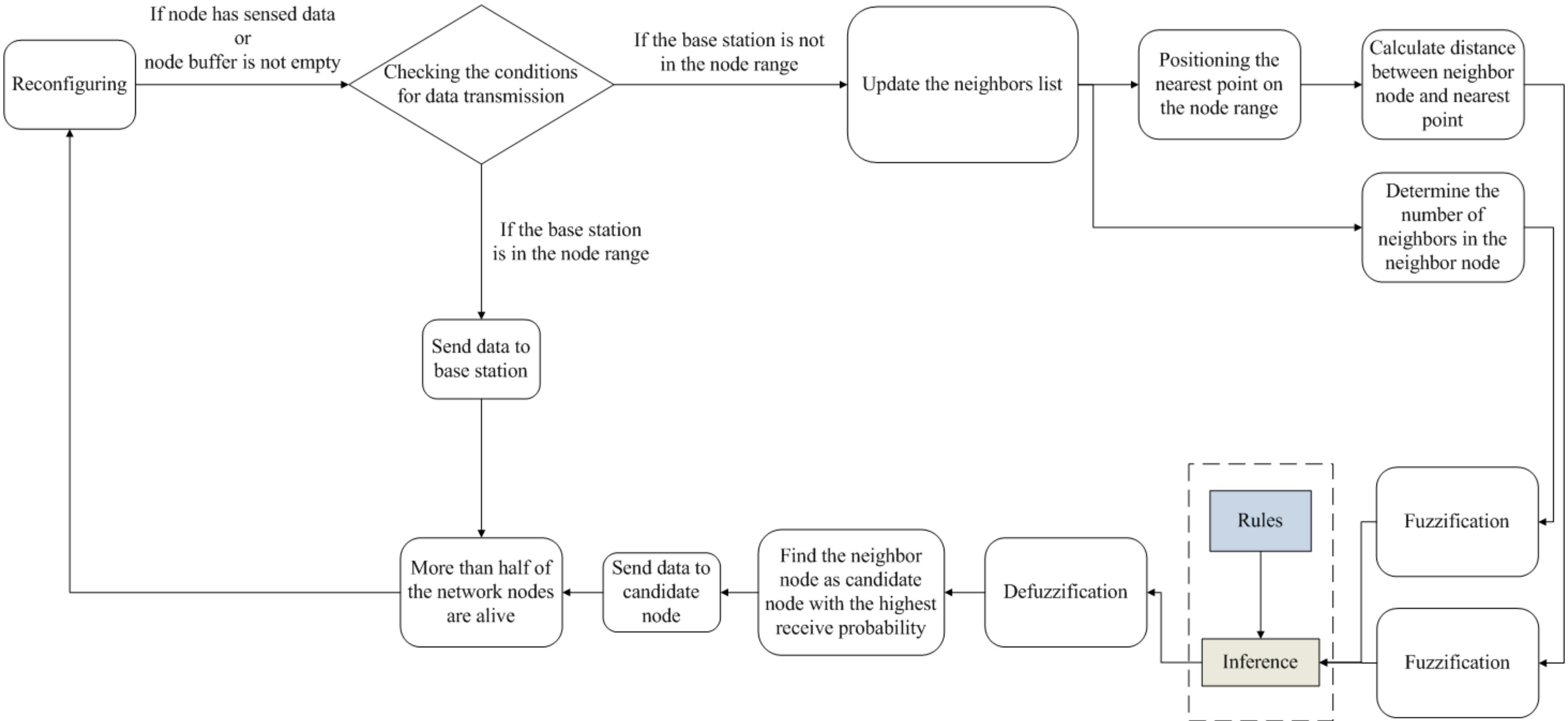
Membership Functions in SFRRTP



Some of the Values in SFRRTP

Node No.	Input parameters		Output parameter
	Receiving probability	Traffic probability	Success probability
1	46.225	53.153	42.571
2	41.572	58.167	46.207
3	48.311	47.668	41.895
4	45.212	52.916	42.549
5	47.962	42.043	42.453

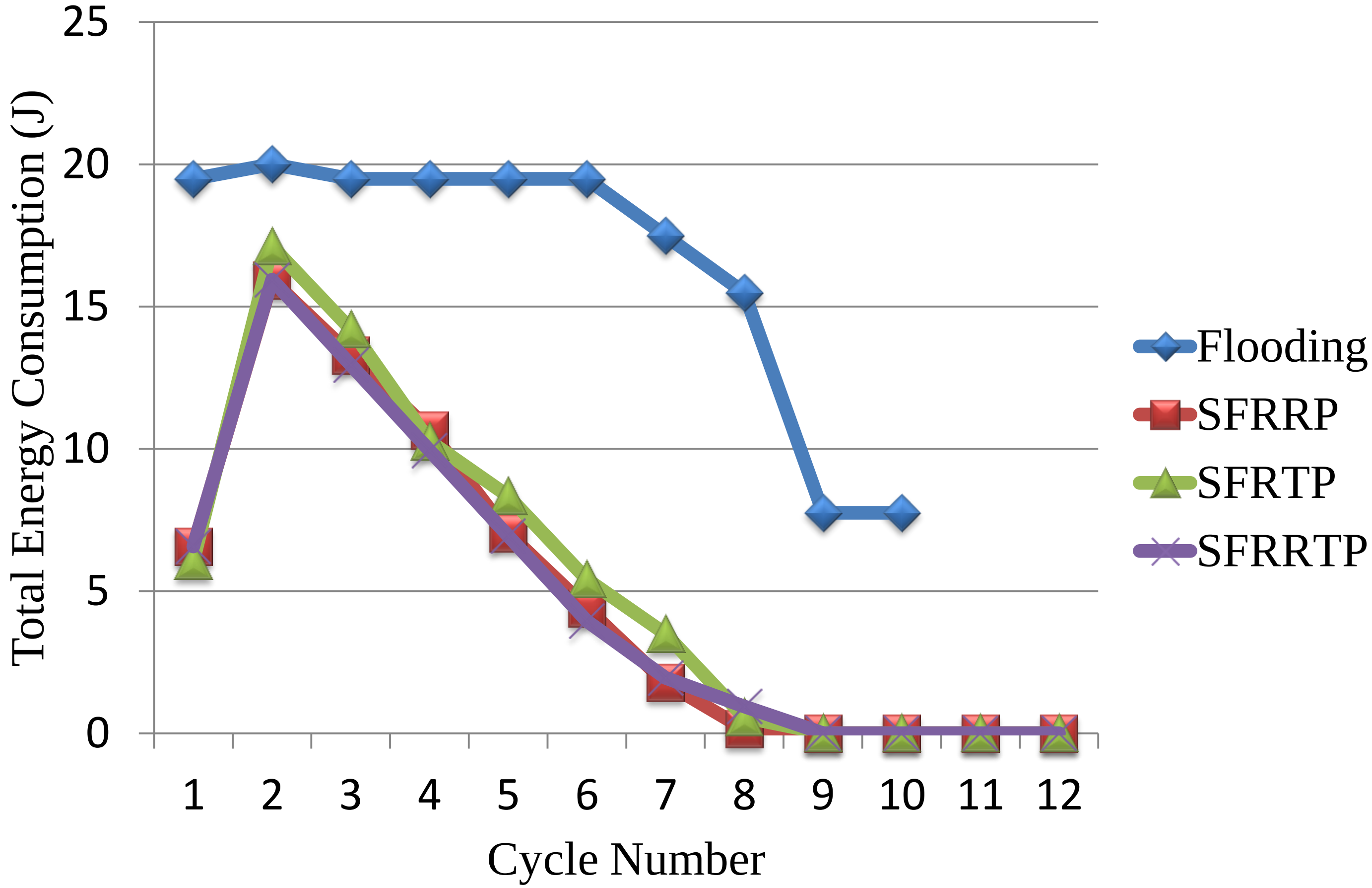
Work Flow of the Protocol SFRRP



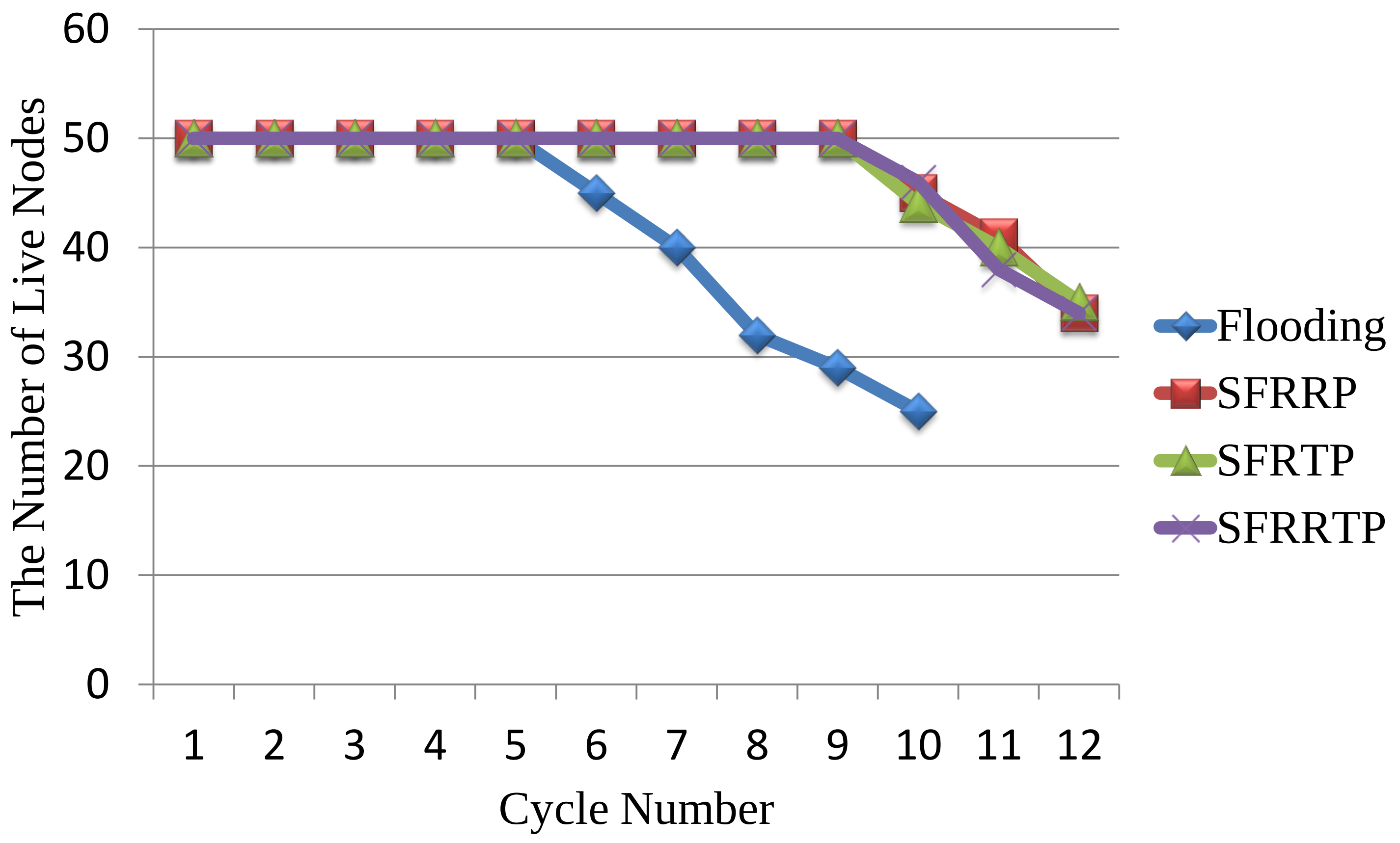
Simulation Parameters in Static 3D Fuzzy Routing Protocols

Parameter	Default value
Topographical area (m^3)	$300 \times 300 \times 300$
The number of nodes	50
Radio range of nodes (m)	75
Initial energy of nodes (J)	5
Data packet size (bit)	10^4
Geographical coordinates of the base station (m)	(150 , 150 , 0)

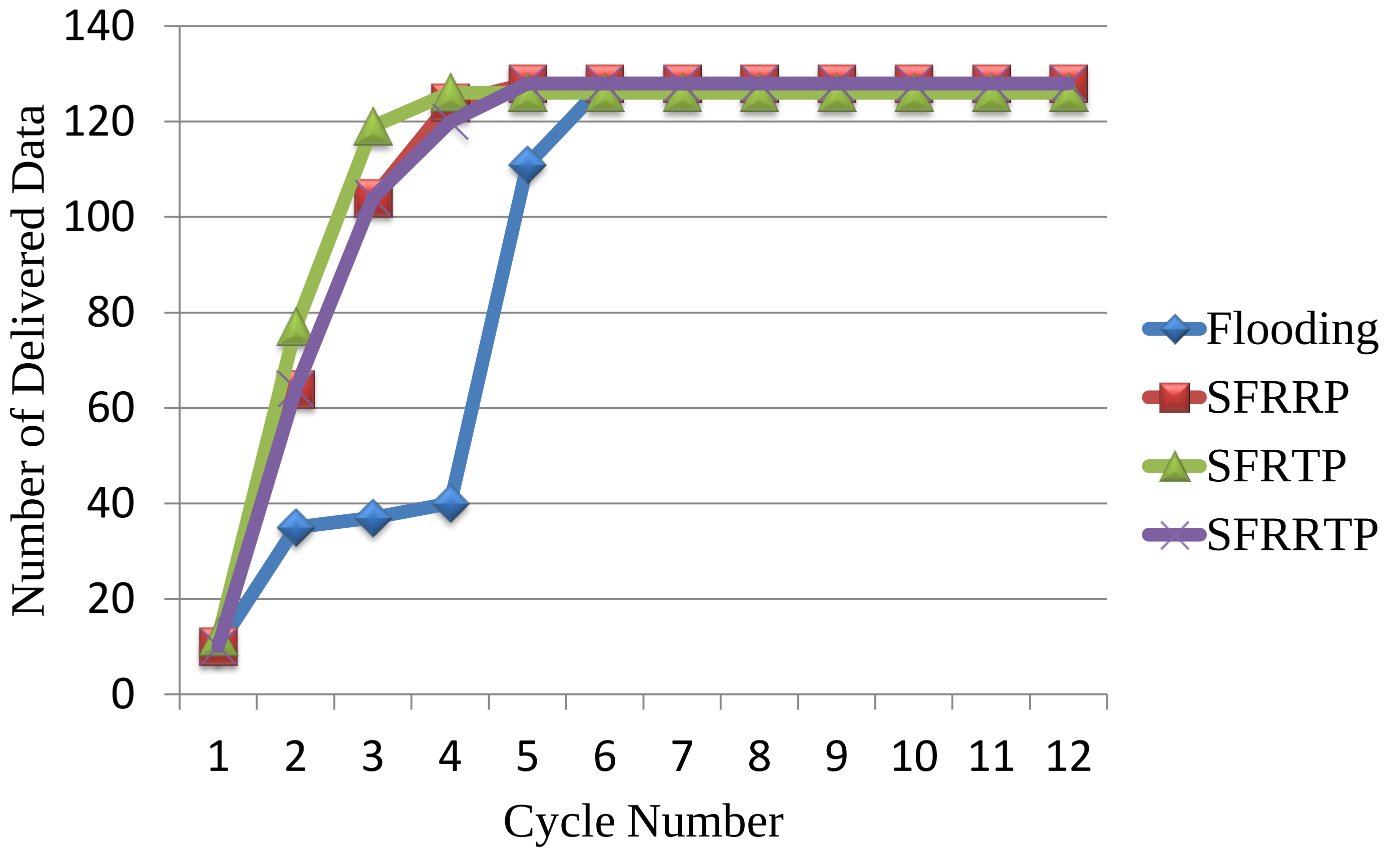
Total Energy Consumption in Static 3D Fuzzy Routing Protocols



The Number of Live nodes in Static 3D Fuzzy Routing Protocols



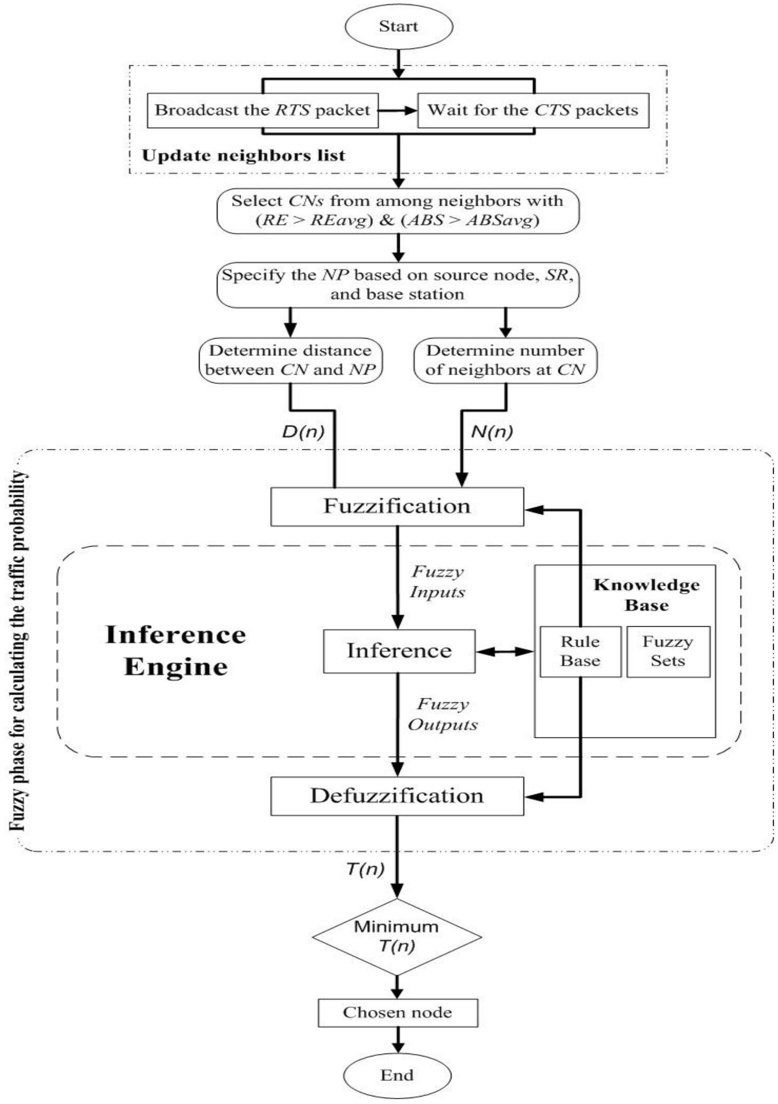
The Number of Delivered Data in Static 3D Fuzzy Routing Protocols



The Effect of Data Generation Rate on the Static 3D Fuzzy Routing Protocols

Data generation rate	Packet delivery ratio				Packet delivery time			
	Flooding	SFRRP	SFRTP	SFRRTP	Flooding	SFRRP	SFRTP	SFRRTP
1000	0.37931	0.9913793	0.982759	0.9913793	7.2273	3.2348	2.9035	3.2522
900	0.34483	0.977612	0.9925373	0.977612	7.95	2.8168	2.9248	2.8321
800	0.33083	0.986667	1	0.986667	7.2273	3.2297	3.5	3.2838
700	0.27957	0.985782	0.976303	0.985782	6.1154	3.3894	3.2233	3.4135
600	0.32353	1	0.9933333	1	7.2273	2.7133	2.7047	2.76
500	0.26818	0.9918367	0.9918367	0.9918367	5.3898	3.3128	3.1893	3.3169
400	0.24055	0.987879	0.984848	0.987879	4.5429	3.3681	3.3015	3.3742
300	0.27244	0.982558	0.997093	0.982558	279	2.8018	2.8921	2.8373
200	0.23282	0.9918301	0.996732	0.9918301	150.69	3.2751	3.1344	3.29
100	0.22068	0.988067	0.9968178	0.988067	211.75	3.2987	3.3081	3.3132

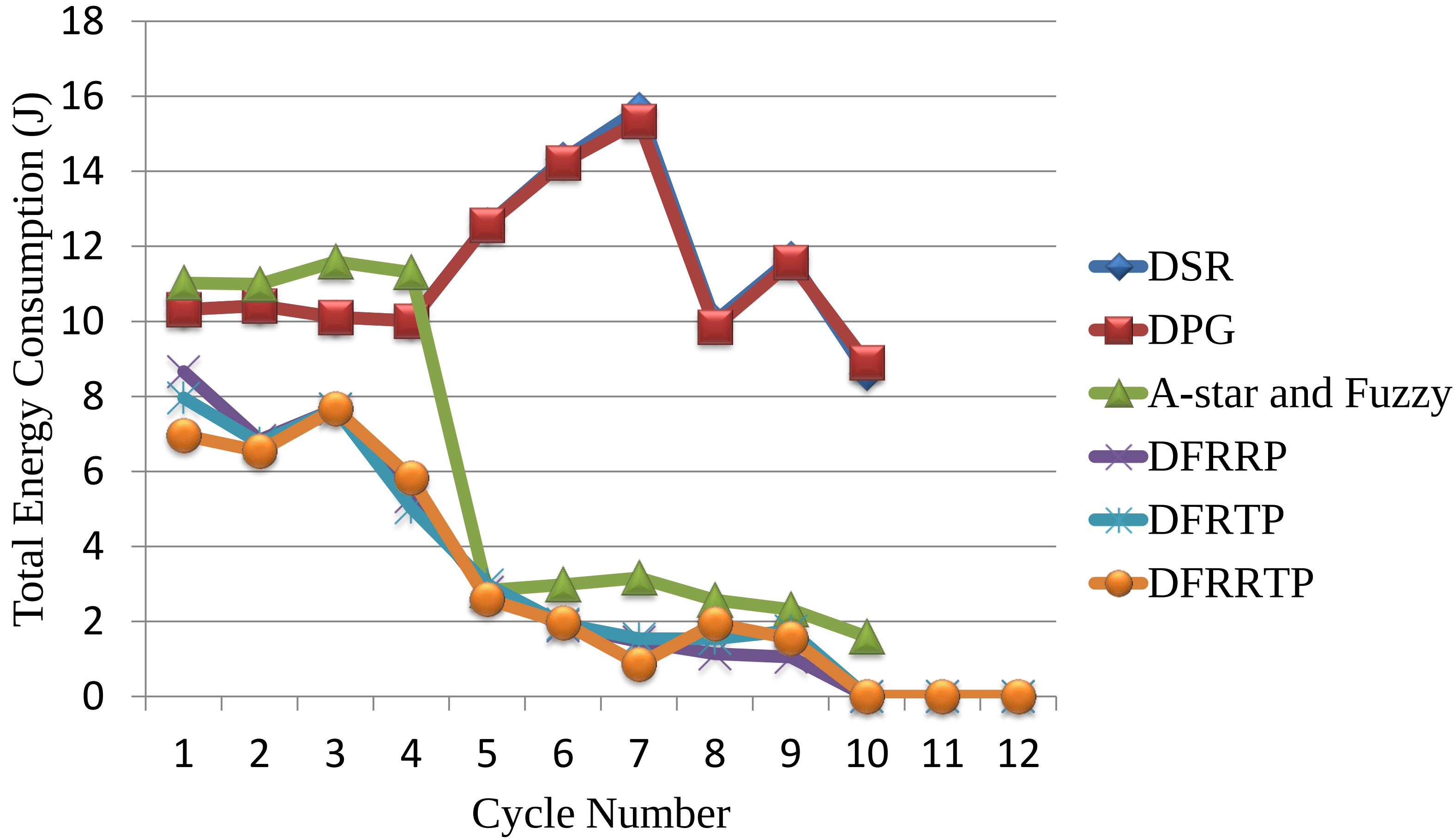
Work Flow of the Protocol DFRTP



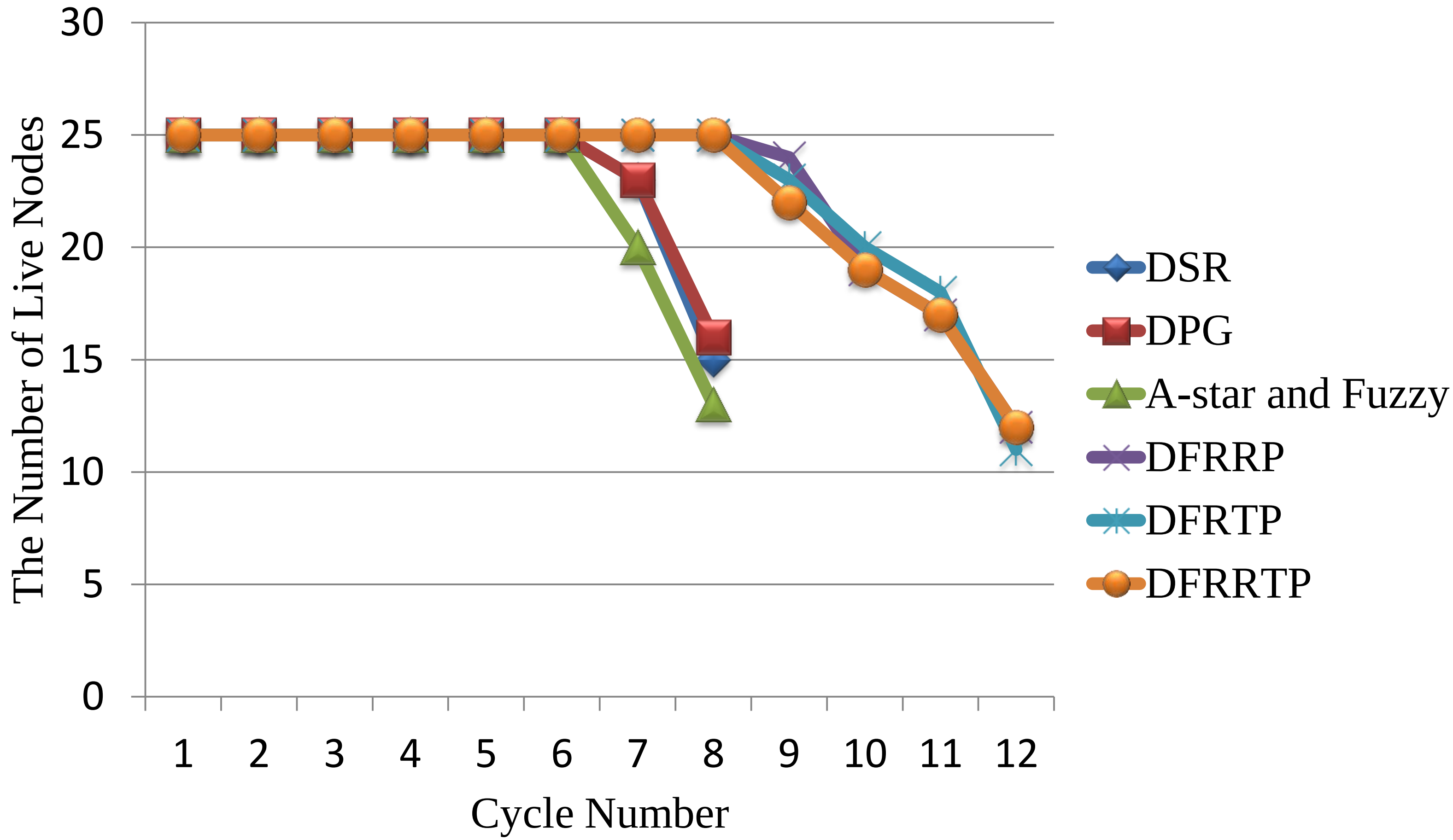
Simulation Parameters in Dynamic 3D Fuzzy Routing Protocols

Parameter	Default value
Topographical area (m^3)	$200 \times 200 \times 200$
The number of nodes	25
Radio range of nodes (m)	80
Initial energy of nodes (J)	5
Data packet size (bit)	10^4
Geographical coordinates of the base station (m)	(200 , 200 , 0)

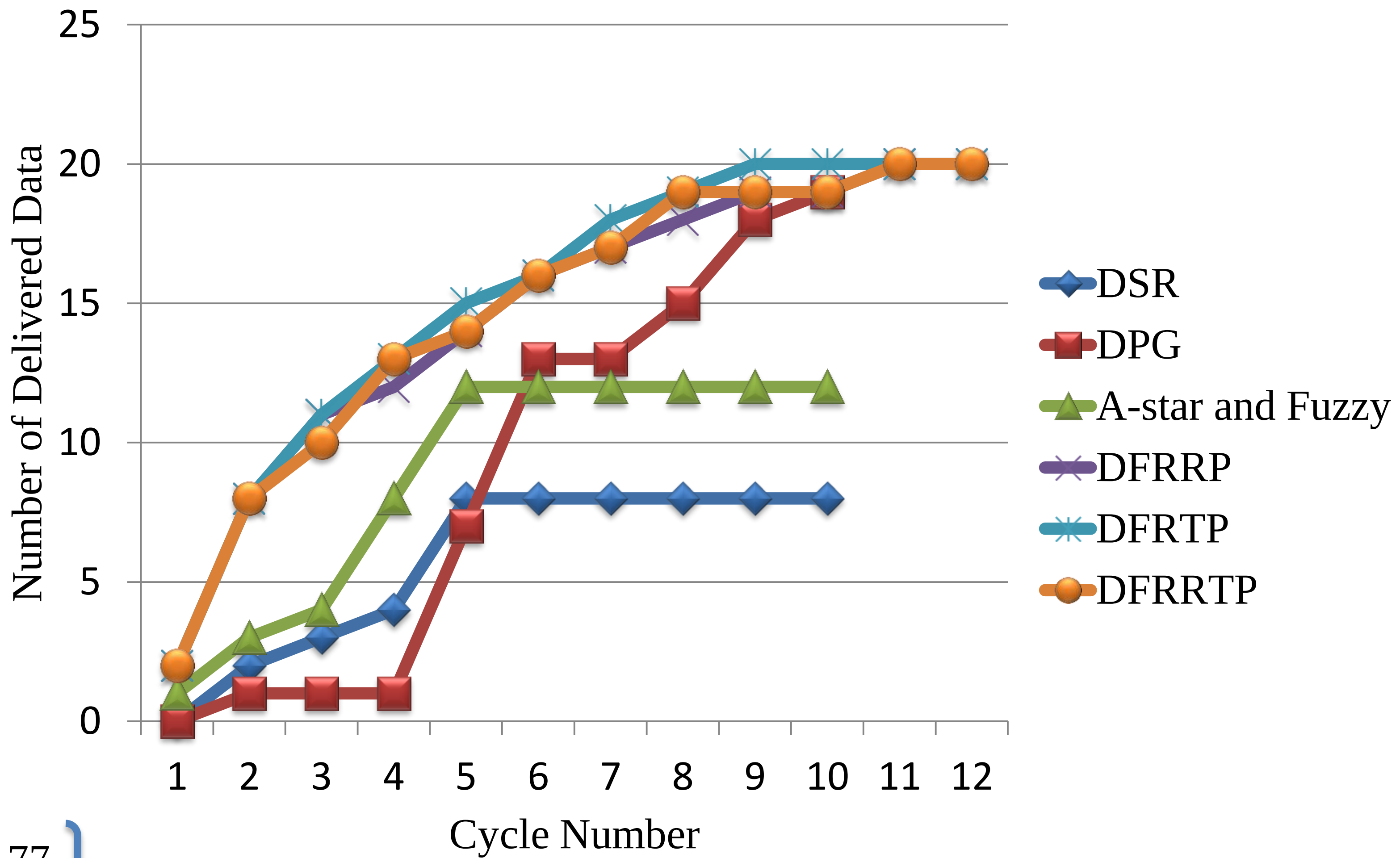
Total Energy Consumption in Dynamic 3D Fuzzy Routing Protocols



The Number of Live nodes in Dynamic 3D Fuzzy Routing Protocols



The Number of Delivered Data in Dynamic 3D Fuzzy Routing Protocols



The Effect of Data Generation Rate on the Dynamic 3D Fuzzy Routing Protocols

Data generation rate	Packet delivery ratio				Packet delivery time			
	DSR	DFRRP	DFRTP	DFRRTP	DSR	DFRRP	DFRTP	DFRRTP
1000	0.125	1	0.875	1	163.5	1.6875	1.0714	1.5
900	0.07692	0.28571	0.42857	0.14286	163.5	0.875	2.0833	0.75
800	0.08	0.52	0.52	0.48	163.5	1.0769	1	1.0833
700	0.08	0.74074	0.7037	0.62963	163.5	1.6	1.7368	1.7059
600	0.07407	0.51852	0.55556	0.51852	163.5	1.0714	2.0667	1.0714
500	0.05556	0.55556	0.61111	0.41667	163.5	1.7	2.1364	1.8
400	0.04651	0.62222	0.64444	0.6	163.5	0.92857	1.3103	0.92593
300	0.0339	0.5	0.54839	0.40323	163.5	1.0968	1.8529	1.04
200	0.02667	0.58974	0.61538	0.5641	163.5	1.4783	1.8125	1.4318
100	0.02	0.52597	0.55195	0.44805	109	1.4321	1.6	1.4493

Determining the State of Sensor Nodes by Fuzzy Decision Making (FAS)

Remaining energy of nodes

- Very low
- Low
- Medium
- High
- Very high

The number of previous active states

- Feeble
- Few
- Medium
- Many
- Lots

Selection priority

- Very low
- Low
- Medium
- High
- Very high

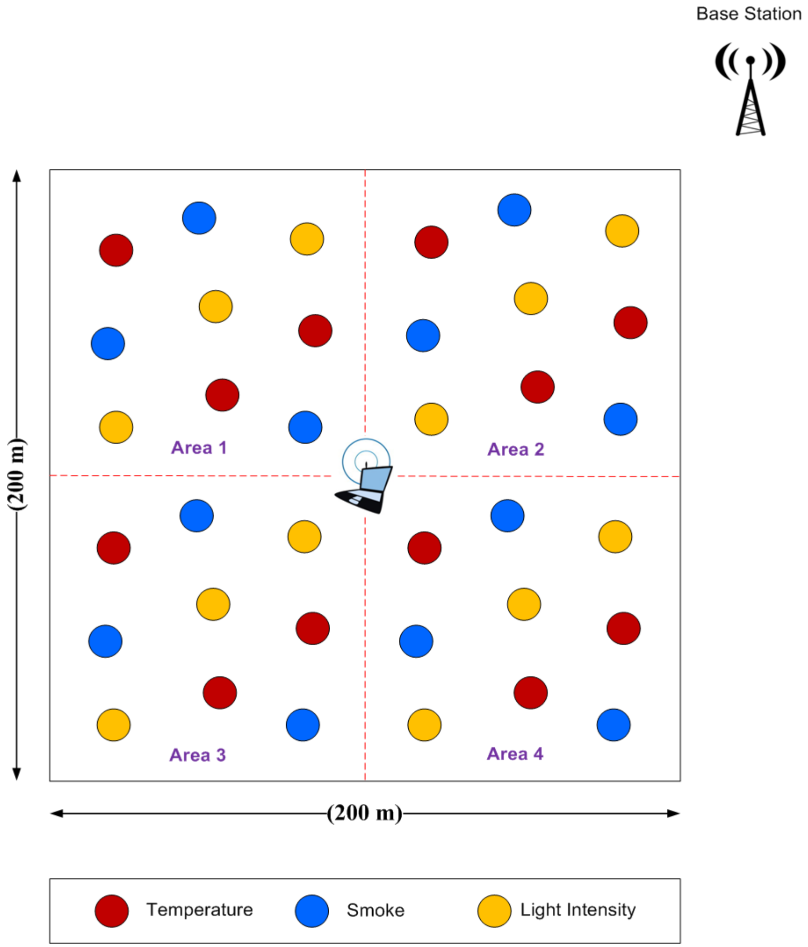
Some of the Fuzzy Rules in FAS

Rule #	Input parameters		Output parameter
	Remaining energy of nodes	The number of previous active states	Selection priority
1	Very low	Feeble	Very low
2	High	Few	High
3	Medium	Medium	Medium
4	Very high	Lots	Low
5	High	Many	Low

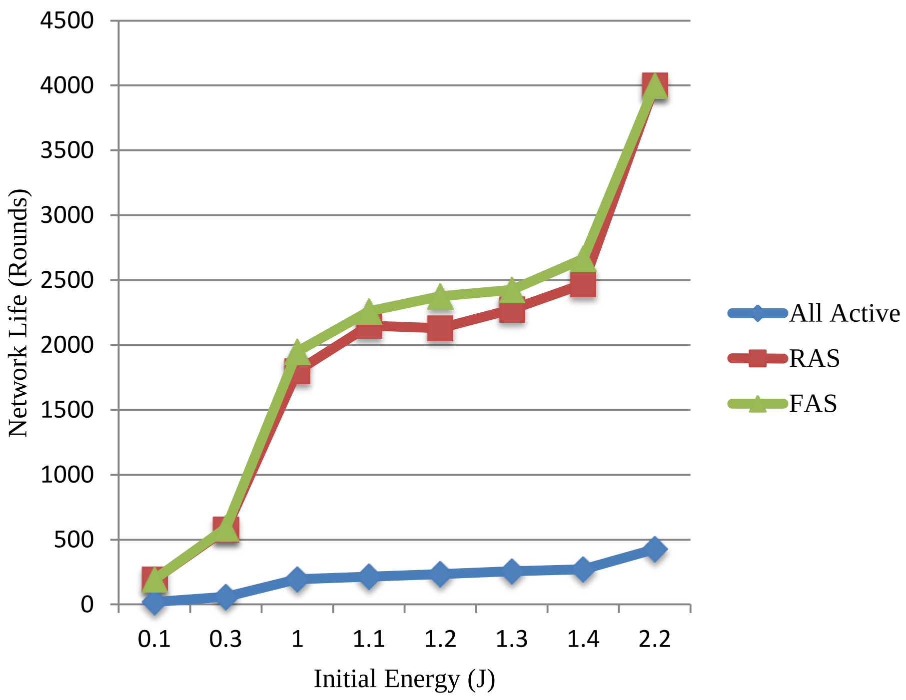
Node No.	Input parameters		Output parameter
	Remaining energy of nodes	The number of previous active states	Selection priority
1	2	11	44.913
2	1.2	15	42.027
3	0.3	5	50.843
4	0.8	2	54.757
5	1.6	8	48.058

Simulation Parameters in FAS

Parameter	Default value
Topographical area (m^2)	200 × 200
The number of nodes	40
Initial energy of nodes (J)	2
Buffer size of the sink	10^4
Data generation rate	5
Period of time to transmit data from sink to base station	20
Geographical coordinates of the sink (m)	(100 , 100)
Geographical coordinates of the base station (m)	(500 , 500)

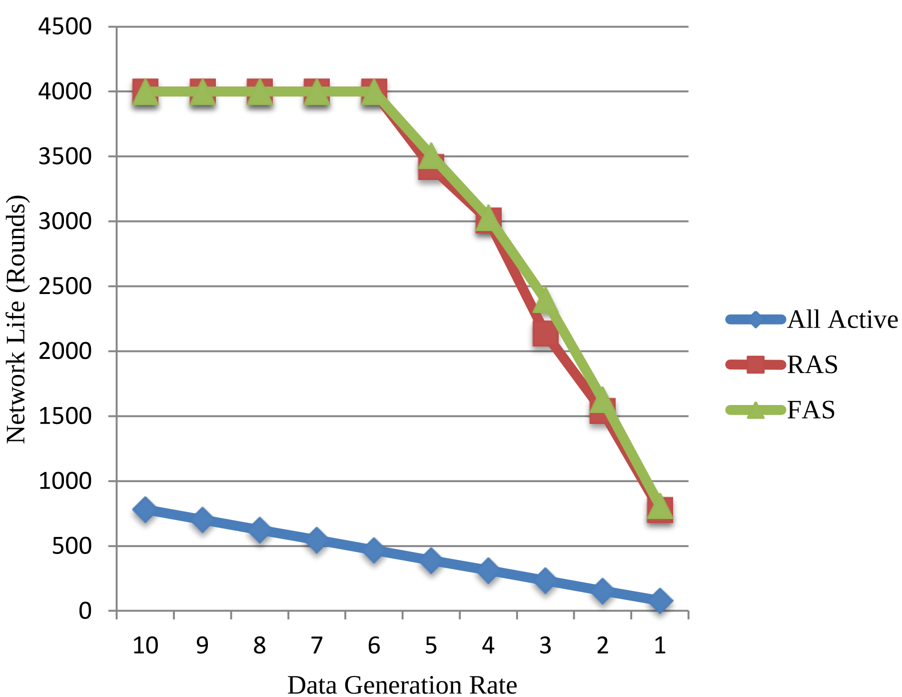


The Effect of Initial Energy in FAS



Initial energy	All Active	RAS	FAS
0.1	20	195	195
0.3	60	580	590
1	195	1800	1950
1.1	215	2150	2260
1.2	235	2130	2375
1.3	255	2275	2425
1.4	270	2470	2665
2.2	425	4000	4000

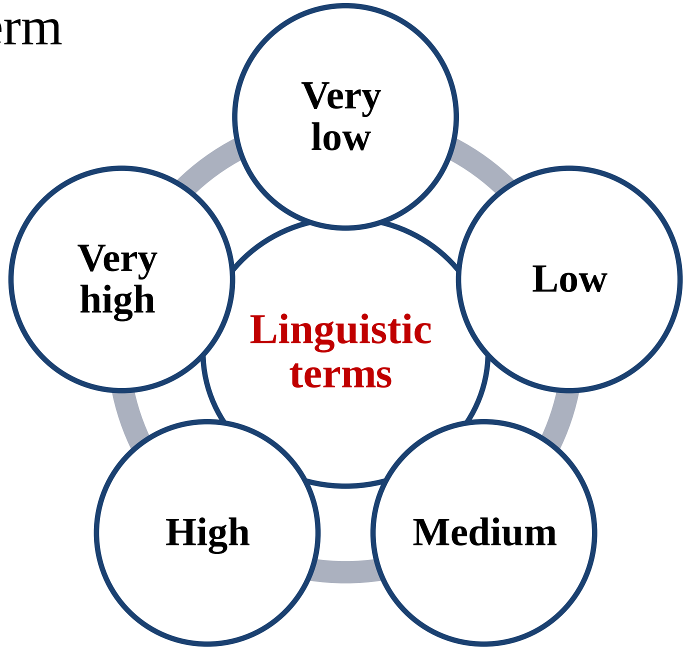
The Effect of Data Generation Rate in FAS



Data generation rate	All Active	RAS	FAS
10	780	4000	4000
9	702	4000	4000
8	624	4000	4000
7	546	4000	4000
6	468	4000	4000
5	390	3420	3510
4	312	3008	3032
3	234	2136	2397
2	156	1540	1628
1	78	778	811

Data Aggregation Methods

- ✓ **Individual data aggregation based on fuzzy logic:** selecting data packets of the linguistic term which has the most data packets
- ✓ **Improved, individual data aggregation based on fuzzy logic:** transmitting only the minimum, average, and maximum values of the selected data in previous method
- ✓ **Fuzzy data aggregation:** transmitting the identifier number or name of the selected linguistic term



Event Detection

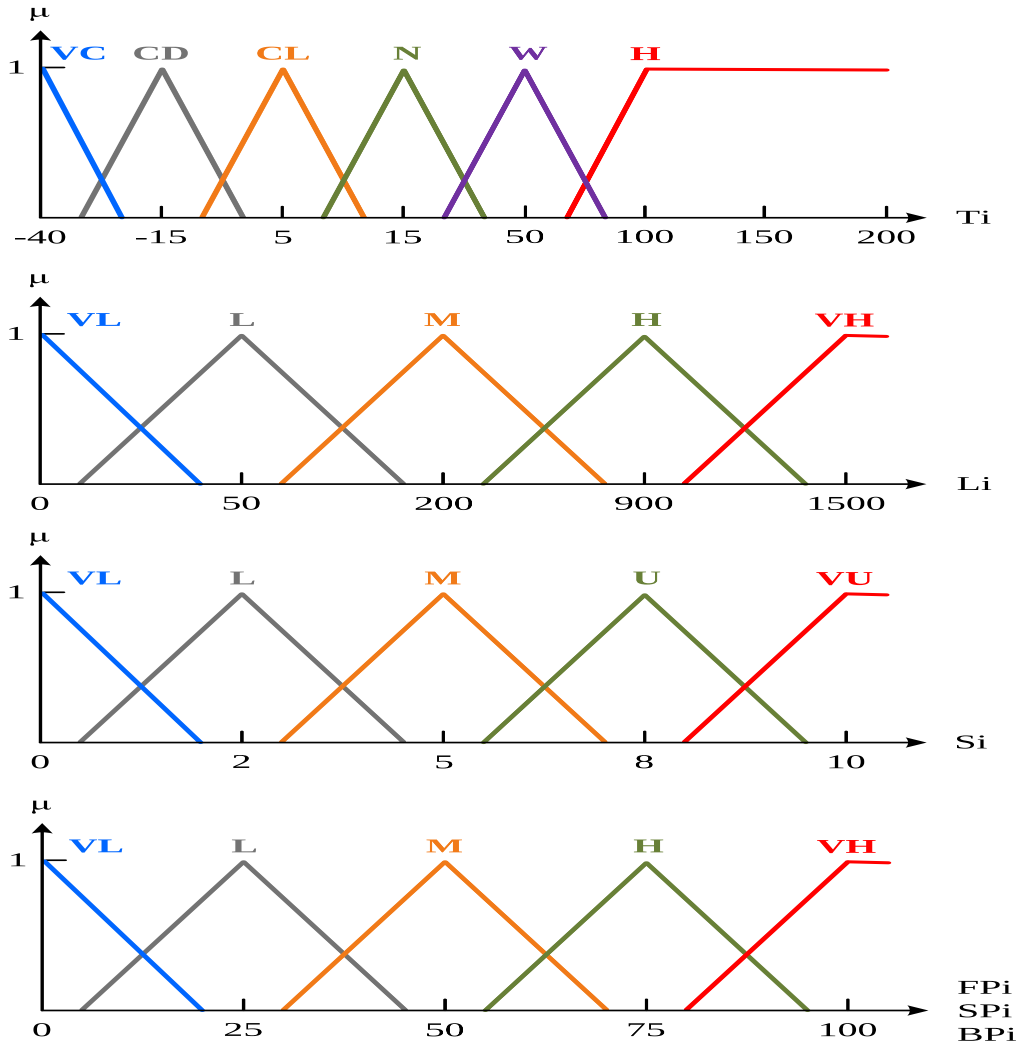
Managers of the sections and common sections are the first nodes to detect various events including fire, suffocation, and burning. Period of time to discover the events is stored in the storage memory of these nodes. This process is conducted by using the individual or fuzzy methods of data aggregation. It uses sensing data of the temperature, photocell, and smoke sensors.

Some of the Fuzzy Rules Used in Event Detection

Input parameters			Output parameters		
Temperature	**Light intensity**	**Smoke**	**Fire probability**	**Suffocation probability**	**Burning probability**
Very cold	Very dark	Very light	Very low	Very low	Very low
Warm	Very bright	Normal	High	Medium	Very high
Cold	Very dark	Heavy	Low	Low	Very low
Cool	Ordinary	Light	Very low	Low	Very low
Nice	Very bright	Normal	Medium	Medium	Medium
Hot	Dark	Heavy	High	High	High

Input parameters			Output parameters		
Temperature	**Light intensity**	**Smoke**	**Fire probability**	**Suffocation probability**	**Burning probability**
35	700	2	40.625	40.625	40.625
20	200	10	75	62.5	75
150	1450	7	76.786	76.22	81.25

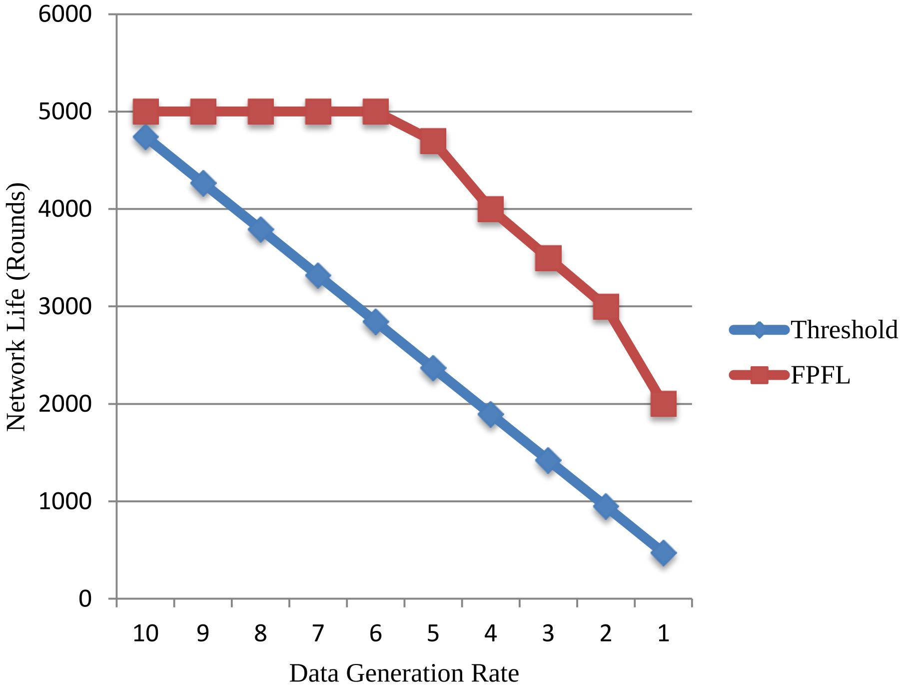
Membership Functions of the Variables in Event Detection

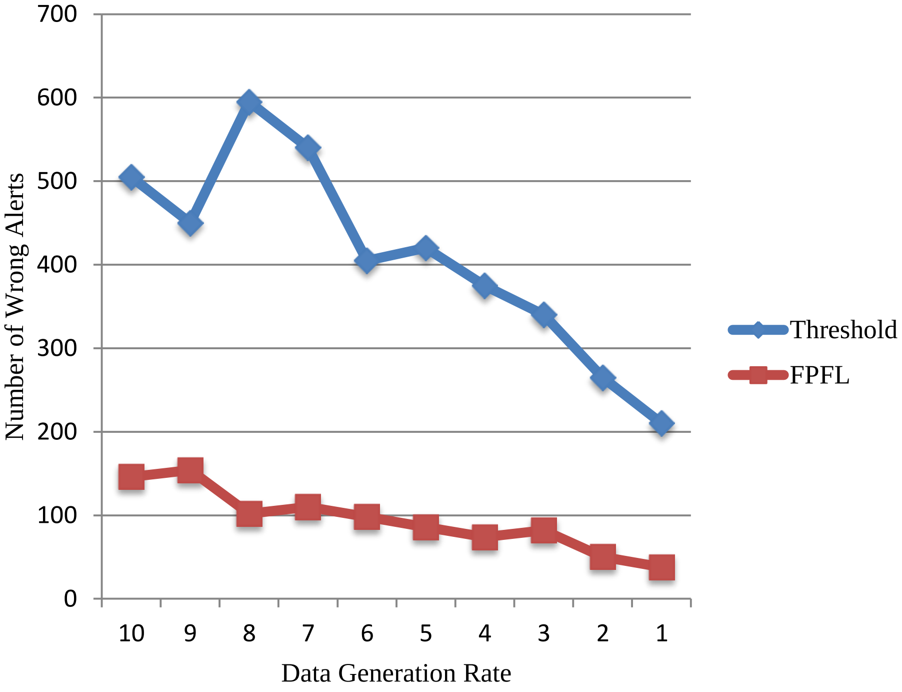


Simulation Parameters to Determine the Fire, Suffocation, and Burning Probabilities

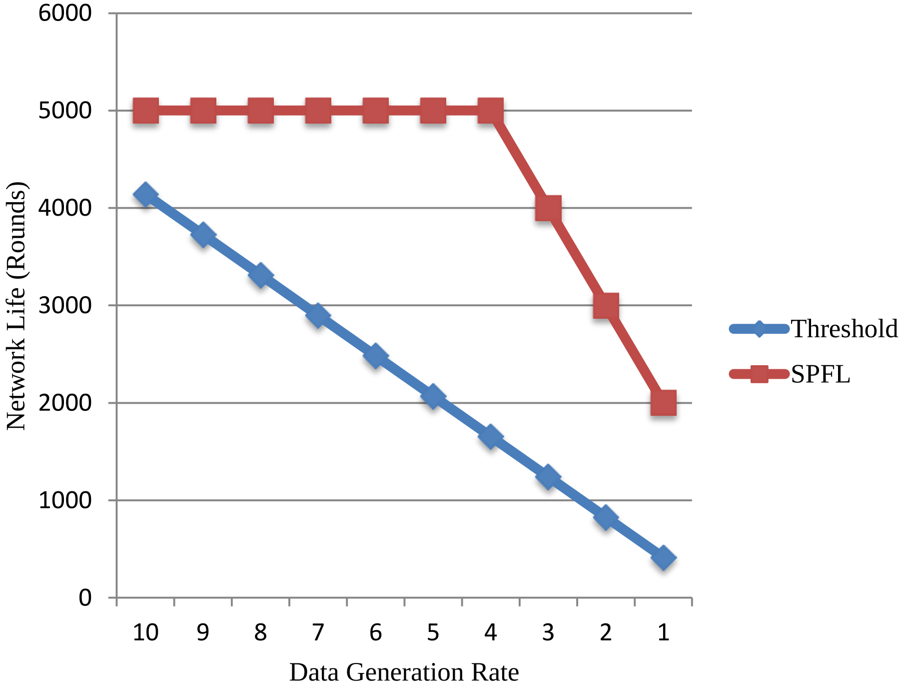
Parameter	Default value
Topographical area (m^2)	200 × 200
The number of nodes	40
Initial energy of nodes (J)	10
Data generation rate	5
Threshold value of the temperature sensor (°C)	50
Threshold value of the smoke sensor (mg/m^3)	8
Threshold value of the photocell sensor (lx)	900
Geographical coordinates of the base station (m)	(100 , 100)

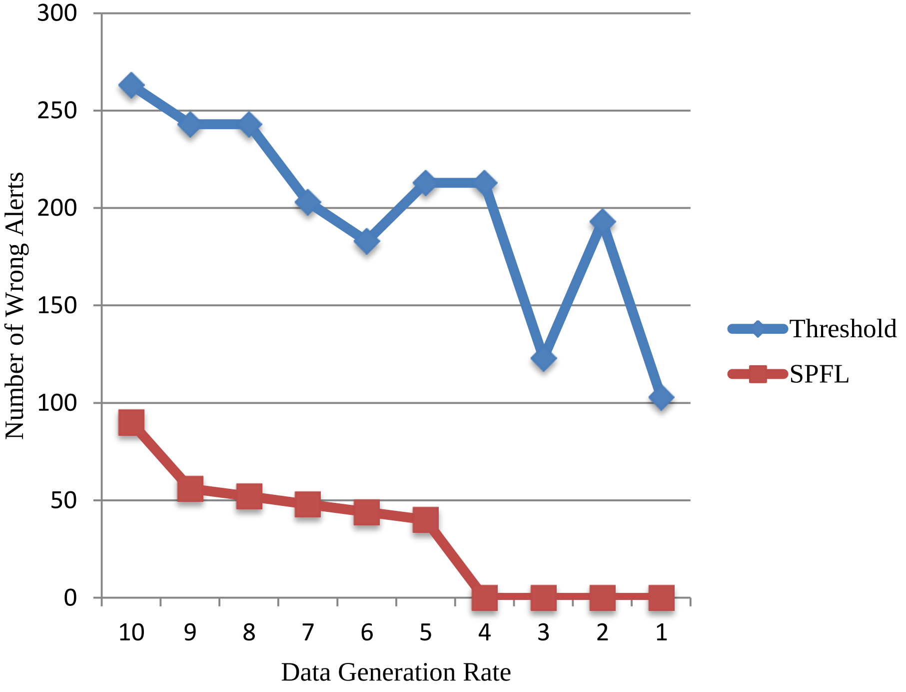
The Effect of Data Generation Rate in Fire Probability



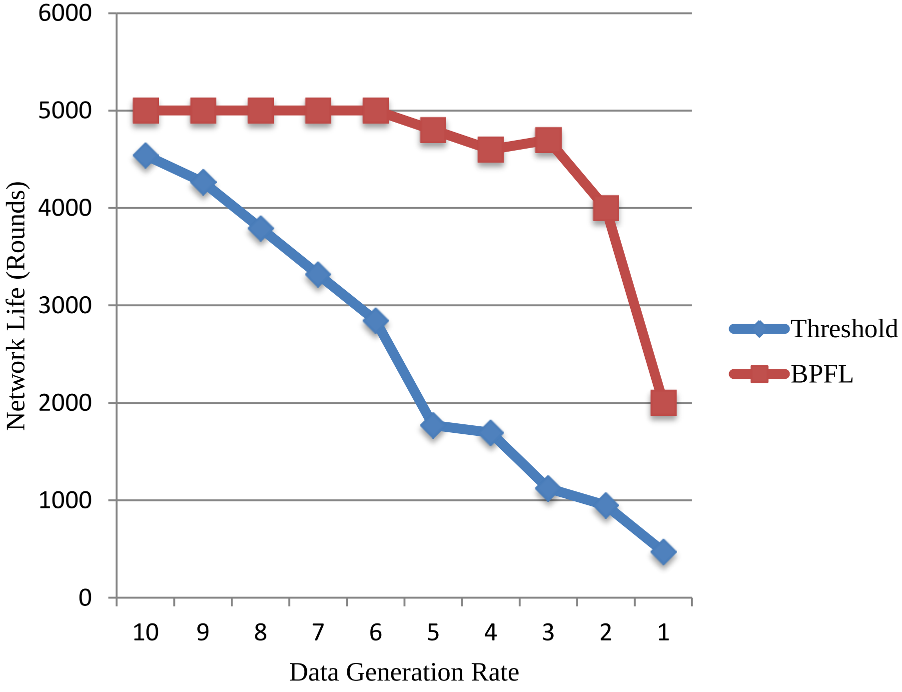


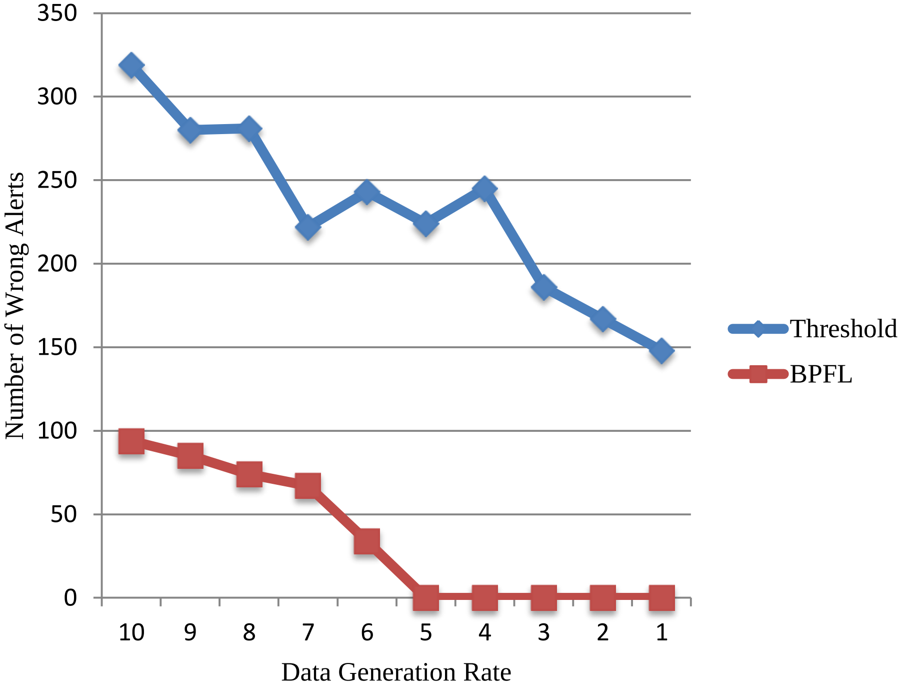
The Effect of Data Generation Rate in Suffocation Probability





The Effect of Data Generation Rate in Burning Probability





Fire Fighting Operations

- Indoor navigation based on fuzzy logic
- Categorizes of the operations
  - To determine the fire volume
  - To determine the fire progress
  - To select the rescue members
  - To determine the number of rescue teams
  - To dispatch the rescue and support teams (agent automobiles)

Indoor Navigation Based on Fuzzy Logic (INFL)

Indoor navigation is one of the main requirements in fire operations. All sections and common sections should be controlled into the environment in order to select the best path to guide all people and appliances to the exit direction. Every path can be composed of several common sections. A fuzzy system is applied to select an appropriate path for this purpose. The ‘passing rate’, ‘distance to event place’ and ‘the number of people’ are the inputs and ‘safe probability’ is the output of this fuzzy system.

Some of Fuzzy Rules in INFL

Input parameters			**Output parameter**
Passing rate	**Distance to event place**	**The number of people**	**Safe probability**
Very limited	Far away	Lots	Very low
Normal	Away	Many	Medium
Heavy	Near	Few	High
Very heavy	Very near	Feeble	Low
Limited	Very near	Feeble	Low

How to Select the Best Path by INFL

P1 = {C1, C3, C4}

P2 = {C1, C4, C5}

P3 = {C2, C3, C4, C5}

Safe probability of each path can be measured by calculating the average of safe probabilities of all the common sections existing into the path. Therefore, safe probability of Path 1 is 54.32, safe probability of Path 2 is 57.117, and safe probability of Path 3 is 52.99975. Finally, Path 2 will be selected as the best path due to have the highest safe probability.

Parameter	Common sections				
	C1	**C2**	**C3**	**C4**	**C5**
Passing rate	60	190	10	110	60
Distance to event place	30	10	50	90	100
The number of people	165	13	35	140	50
Safe probability	58.036	50	48.684	56.25	57.065

To Determine the Fire Volume Based on Fuzzy Logic (FVFL)

Input parameters			Output parameter
Temperature	**Light intensity**	**Smoke**	**Fire volume**
Cold	Bright	Heavy	Medium
Hot	Ordinary	Heavy	High
Warm	Very dark	Normal	Low
Very cold	Ordinary	Normal	Low
Nice	Very bright	Normal	High
Cool	Very dark	Very heavy	Low

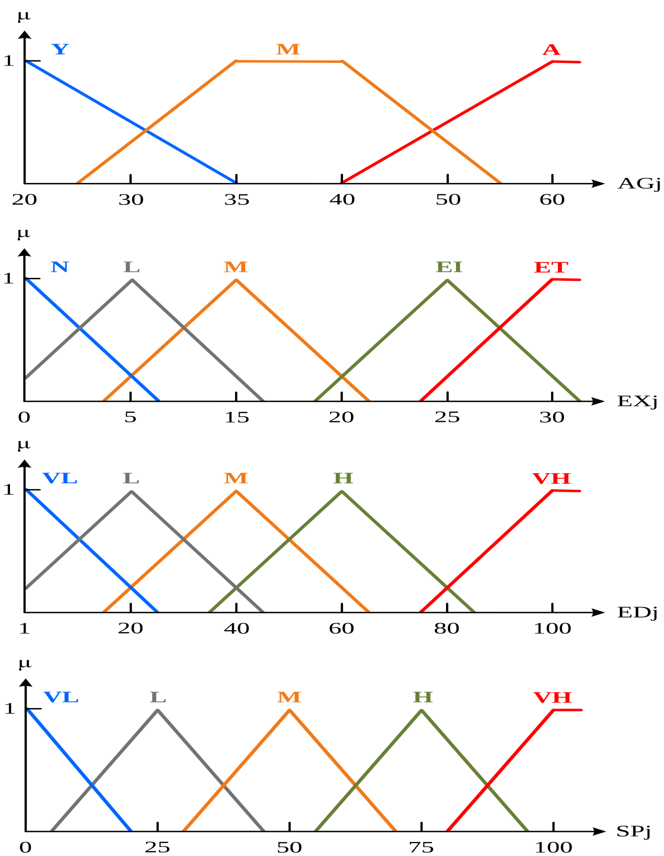
Input parameters			Output parameter
Temperature	**Light intensity**	**Smoke**	**Fire volume**
-10	700	3	50
25	900	5	74.286
140	1400	7	81.429

To Determine the Fire Progress Based on Fuzzy Logic (FPFL)

Input parameters		**Output parameter**
The difference of fire volume	**Interval time**	**Fire progress**
Decreasing	Very low	Decreasing
Normal	Low	Very high
Partial	Medium	Increasing
Considerable	High	Very high
No change	High	Stable

Input parameters		**Output parameter**
The difference of fire volume	**Interval time**	**Fire progress**
-5	55	164.73
20	5	227.16
40	10	268.52

To Select Members of the Rescue Team Based on Fuzzy Logic (SRTFL)



Input parameters			Output parameter
Age	**Experience**	**Fire volume**	**Success probability**
Young	Beginner	Very low	Very high
Young	Low experience	Low	High
Middle-aged	Normal	Very high	High
Middle-aged	High experience	High	Very high
Old	Expert	Medium	Very high

Member No.	Input parameters			Output parameter
	Age	**Experience**	**Fire volume**	**Success probability**
1	30	8	60	40
2	40	15	45	55.435
3	50	25	25	52.335

To Determine the Number of Rescue Teams Based on Fuzzy Logic (DNRTFL)

Input parameters		Output parameter
Fire volume	**Fire progress**	**The number of teams**
Very low	Decreasing	Normal
Low	Stable	Emergency
Medium	Increasing	Critical
High	Very high	Many
Very high	Decreasing	Lots

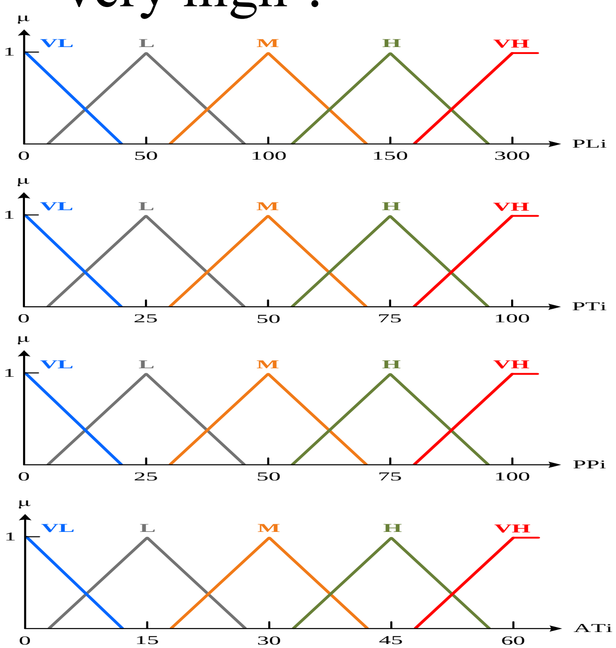
Input parameters		Output parameter
Fire volume	**Fire progress**	**The number of teams**
50	164	10
74	227	10
25	268	7

Dispatching Method of the Rescue Teams Based on Fuzzy Logic (DMRTFL)

There are various paths from local fire department or main fire department to event place. Hence, an appropriate path should be selected to dispatch the rescue agent automobiles. This method can also be used to dispatch rescue teams of the other fire departments toward the event place. It uses ‘path length’, ‘path traffic’, ‘passage probability’ and ‘arrival time’ to select the best path from among a list of all possible paths.

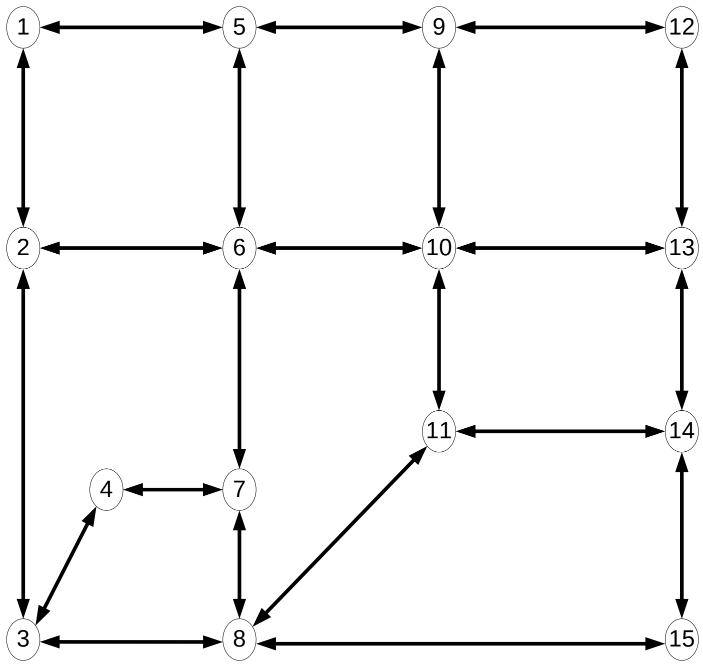
Dispatching Method of the Rescue Teams Based on Fuzzy Logic (DMRTFL)

Linguistic terms for ‘path length’ and ‘arrival time’ are ‘feeble’, ‘few’, ‘normal’, ‘many’ and ‘lots’. Moreover, linguistic terms for ‘path traffic’ and ‘passage probability’ are ‘very low’, ‘low’, ‘medium’, ‘high’ and ‘very high’.



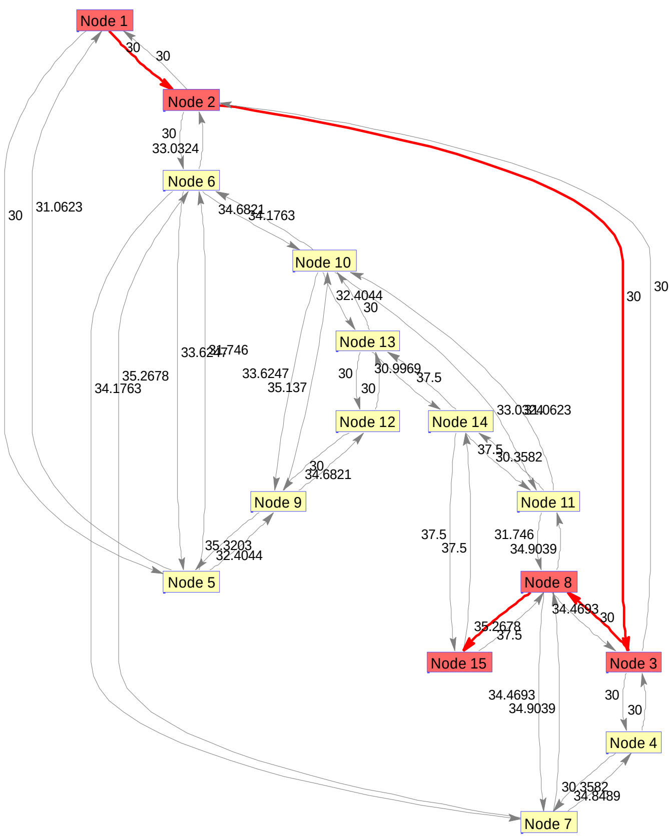
Input parameters			Output parameter
Path length	**Path traffic**	**Passage probability**	**Arrival time**
Normal	High	High	Normal
Feeble	Medium	Low	Feeble
Lots	Low	Medium	Many
Few	Medium	Medium	Normal
Many	High	Very low	Feeble

Simulation and Evaluation of the Dispatching Methods



Source	Destination	Input parameters				Output parameter
		Path length (m)	Path traffic (%)	Passage probability (%)	Arrival time (min)
1	2	1	95	3	30
1	5	6	85	5	30
5	9	59	63	27	32.404
6	10	74	55	35	34.682
10	11	164	29	63	33.032
10	13	170	27	65	32.404
8	3	89	47	45	34.469
15	14	295	1	100	37.5
4	3	38	71	19	30
12	9	195	19	75	30

Simulation and Evaluation of the Dispatching Methods



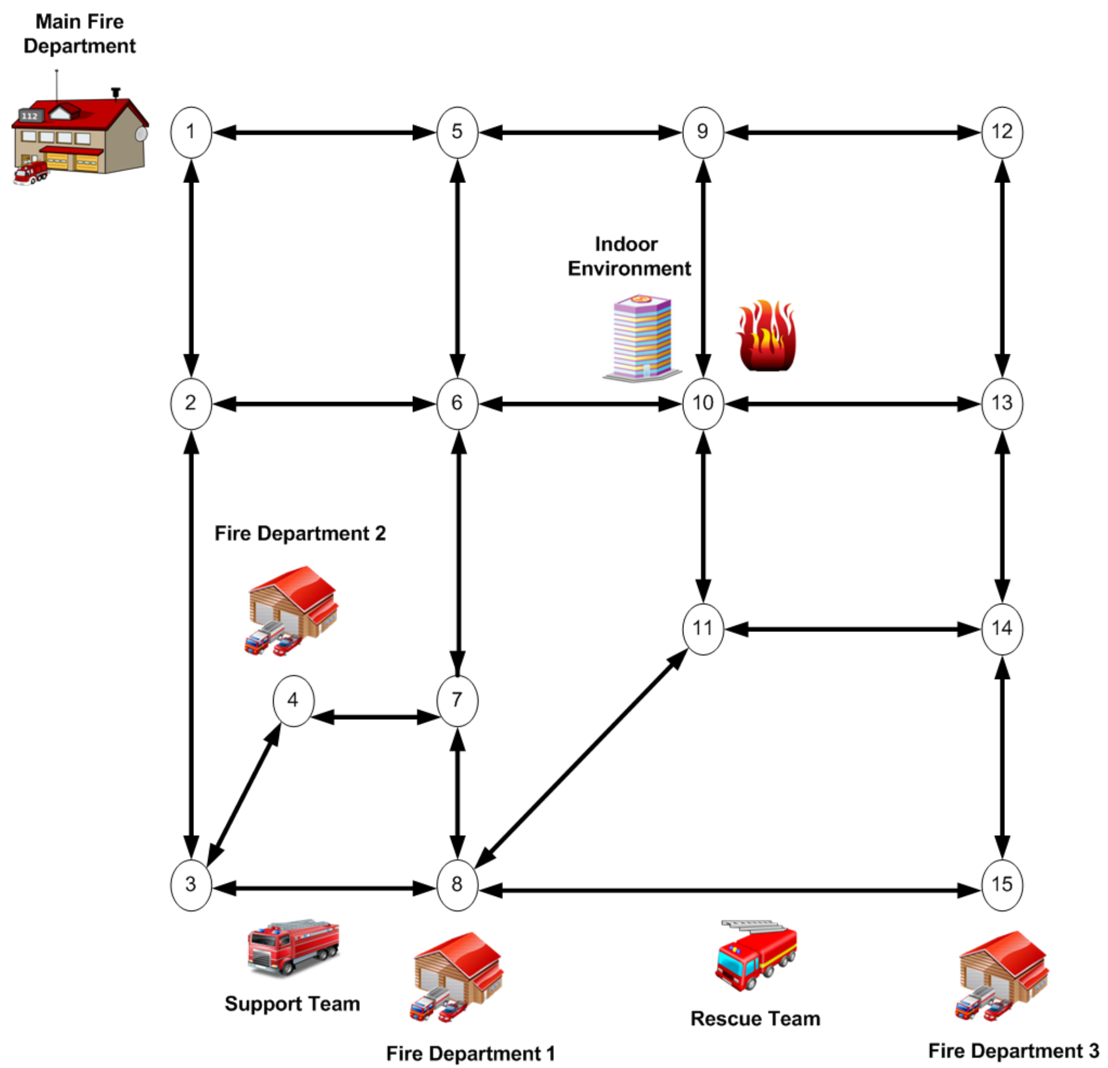
Source	Destination	Input parameters			Output parameter
		Path length (min)	Path traffic (min)	Passage probability (min)	Arrival time (min)
2	10	64.682	64.682	64.682	64.682
4	15	95.268	100.53	95.268	95.268
13	5	97.801	95.32	97.801	95.32
8	9	156.87	170.27	156.87	99.591
8	5	124.47	205.59	124.47	103.36
12	11	98.169	98.497	98.169	93.032
10	8	127.21	138.4	127.21	64.778
8	13	161.56	110.27	161.56	98.371
15	6	131.97	139.18	131.97	107.24
5	15	156.33	165.58	156.33	136.09
12	8	186.38	136	186.38	124.78

Determining the Fault Probability of Nodes Based on Fuzzy Logic (FPNFL)

Input parameters			Output parameter
The number of events	Maximum volume of the events	Remaining energy of nodes	Fault probability
Ordinary	Noticeable	High	Medium
Feeble	Normal	Low	High
Few	Normal	Medium	Low
Many	Slight	Low	High
Lots	Partial	Very low	Very high

Node No.	Input parameters			Output parameter
	The number of events	Maximum volume of the events	Remaining energy of nodes	Fault probability
1	15	55	28	43.878
2	25	15	34	50
3	50	65	48	37.918
4	45	45	23	37.5
5	27	60	4	46.934

A Case Study to Evaluate the Proposed Fire System



Financial and Human Losses in Dispatching Not Enough Agent Automobiles to the Event Place

Event #	Fire volume (m^2)	Fire progress	The number of required teams		Financial losses (per minute)	Total financial losses	Human losses (per hour)		Total human losses	
			Random method	The proposed DNRTFL			The number of dead humans	The number of injured humans	The number of dead humans	The number of injured humans
1	50	164	6	10	$4,000	$480,000	1	2	2	4
2	25	268	4	7	$3,000	$360,000	5	6	10	12
3	55	360	8	9	$6,000	$720,000	4	3	8	6
4	70	700	12	16	$4,000	$480,000	2	8	4	16
5	80	560	10	14	$5,000	$600,000	3	4	6	8

Selecting an Appropriate Fire Department to Dispatch Support Agent Automobiles to the Event Place

Fire department	Dispatching methods							
	Path length		**Path traffic**		**Passage probability**		**The proposed DMRTFL**	
	Arrival time (min)	*Path*	*Arrival time (min)*	*Path*	*Arrival time (min)*	*Path*	*Arrival time (min)*	*Path*
Main Fire Department	94.682	1-2-6-10	97.541	1-5-9-10	94.682	1-2-6-10	94.682	1-2-6-10
Fire Department 1	129.15	8-3-2-6-10	140.27	8-15-14-13-10	129.15	8-3-2-6-10	65.966	8-11-10
Fire Department 2	124.68	4-3-2-6-10	100.31	4-7-6-10	124.68	4-3-2-6-10	100.31	4-7-6-10

Conclusions

In this thesis, a smart fire system was proposed that can monitor, control, report, and perform the required operations in the indoor and outdoor environments. Static 3D fuzzy routing protocols were used to transmit data packets between stationary sensor nodes placed in the environment. Data transmissions between agent automobiles and rescue members were done by dynamic 3D fuzzy routing protocols. Moreover, agent automobiles can dispatch from fire departments to event places through appropriate paths by using the proposed fuzzy system. Members of the agent automobiles and rescue teams could also be selected by fuzzy system. Determining the fire probability, suffocation probability, burning probability, and fault probability of nodes are other features of this system.

Future Works

- To enhance fault tolerance of sensor nodes
- Data transmission between mobile nodes via the base station
- Data transmission from sensor nodes to the base station via multiple paths based on fuzzy logic

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- M.S. Gharajeh. Determining the State of the Sensor Nodes Based on Fuzzy Theory in WSNs. International Journal of Computers Communications & Control (Impact Factor: 0.694), 2014, Vol. 9, No. 4, pp. 419-429.
- M.S. Gharajeh. SFRRP: 3D Fuzzy Routing for Wireless Sensor Networks, in: Advances in Control and Mechatronic Systems, Volume: I. United Scholars Publications, January 18, 2016, pp. 87-108.
- M.S. Gharajeh, S. Khanmohammadi. Dispatching Rescue and Support Teams to Events Using Ad Hoc Networks and Fuzzy Decision Making in Rescue Applications. Journal of Control and Systems Engineering, 2015, Vol. 3, No. 1, pp. 35-50.
- M.S. Gharajeh, S. Khanmohammadi. DFRTP: Dynamic 3D Fuzzy Routing Based on Traffic Probability in Wireless Sensor Networks. IET Wireless Sensor Systems, 2016, Vol. 6, No. 6, pp. 211-219.
- M.S. Gharajeh. FSB-System: A Detection System for Fire, Suffocation, and Burn Based on Fuzzy Decision Making, MCDM, and RGB Model in Wireless Sensor Networks. International Journal of Sensor Networks, 2017 ***(under review)***.

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