Clustering and Detecting Network Intrusion Based on Fuzzy Algorithms

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الملخص

العنقدة (تحليل العنقود) تستخدم بشكل واسع في تحليل البيانات وتمييز الأنماط. هناك خوارزميات عدة لعنقدة مجاميع البيانات الكبيرة أو سيل من مجاميع البيانات، أهدافها تنظيم مجاميع البيانات في عناقيد، وعناصر البيانات هذه الموجودة في العنقود الواحد تشبه بعضها البعض الآخر وتكون مختلفة عن عناصر البيانات في عناقيد أخرى. لقد تم تطبيق خوارزميات العنقدة المضببة الثلاث FCM, PCM, GK باستخدام بيانات الـــ KDD cup 99 لتصنيف التطفل إلى 23 صنفاً طبقا لاسم الهجمة التابعة لنوع الهجوم الرئيسي، وكذلك طبقت هذه الخوارزميات الثلاث لتصنيف التطفل إلى 5 أصناف طبقا لنوع الهجوم الرئيسي ومن ثم تم تقييم أداء النظام عن طريق احتساب نسبة التصنيف والكشف والتحذير الكاذب لهذه البيانات. وأخيرا كانت النتائج التي تم الحصول عليها كفوءة وبنسبة تصنيف 100% والتي لم يتم الحصول عليها في أعمال سابقة.

ABSTRACT

Clustering or (cluster analysis) has been widely used in data analysis and pattern recognition. There are several algorithms for clustering large data sets or streaming data sets, Their aims to organize a collection of data items into clusters. These such items are more similar to each other within cluster, and difference than they are in the other clusters. Three fuzzy clustering algorithms (Fuzzy C-Means, Possibilistic C-Means and Gustafson-Kessel algorithms) were applied using kdd cup 99 data set to classify this data set into 23 classes according to the subtype of attacks. The same data set were classified into 5 classes according to the type of attacks. In order to evaluate the performance of the system, we compute the classification rate, detection rate and false alarm rate on this data set. Finally, the results obtained from the experiments with classification rate 100% which has not been obtained in any previous work.

1- Introduction

An intrusion detection system(IDS) is a component of the information security framework. Its main goal is to differentiate between normal activities of the system and behavior that can be classified as suspicious or intrusive. The goal of intrusion detection is to build a system which would automatically scan network activity and detect such intrusion attacks. Once an attack is detected, the system administrator can be informed who can take appropriate action to deal with the intrusion [12]. Intrusion detection techniques can be categorized into misuse detection and anomaly detection .

- misuse detection uses the patterns of well-known attacks or vulnerable spots in the system to identify intrusions [4]. Misuse detection is based on the knowledge of system vulnerabilities and known attack patterns. Misuse detection is concerned with finding intruders who are attempting to break into a system by exploiting some known vulnerability, ideally, a system security administrator should be a were of all the known vulnerabilities and eliminate them [3].
- Anomaly detection attempts to determine whether can be flagged as intrusions.

There are three types of intrusion detection systems: Host-based Intrusion Detection System (HIDS), Network-based Intrusion Detection System (NIDS), and combination of both types (Hybrid Intrusion Detection System). HIDS usually observes log or system –call on a single host, A host –based intrusion detection system places its reference monitor in the kernel / user layer and watches for anomalies in the system call patterns. While a NIDS typically monitors traffic flows and network packets on network segment, and thus observes multiple hosts simultaneously, NIDS performs traffic analysis on a local area network [12][4].

This research is organized as follows: in section 2 previous work 3 fuzzy clustering algorithms are discussed, section 4 (Knowledge Discovery and Data Mining) kdd data set used in this research, section 5 Data proeprocessing, section 6 describes about the experiments and results obtained, and section 7 is conclusions .

2- Previous Work

In particular several clustering algorithms based approaches were employed for intrusion detection. Jawhar and Mehrotra [7] used fuzzy c-means clustering to classified dataset into 2 classes, they used (22133)records, the classification result in training stage is 99.9. Siddiqui[14] used parallel backpropagation neural network and pararllel fuzzy ARTMAP, the detection rate result for parallel BP in the training stage is 98.36 and the detection rate in the testing stage is 81.73 and false alarm is 1.28. Detection rate for parallel fuzzy ARTMAP in training stage is 80.14 and in testing state detection rate is 80.52 and false alarm is 19.48.

3- Fuzzy Clustering Algorithms

3-1 Fuzzy C-Means Algorithm

The Fuzzy C-Means algorithm (FCM) is introduced by Bezdek [12]. Fuzzy c-means is based on Euclidean distance function [9]. It is a data clustering technique where each data point belongs to a cluster to some degree that is specified by membership grade [18]. Let $X=\{x_1,\ldots x_j,\ldots x_n\}$ be the set of n objects and $V=\{v_1,\ldots v_i,\ldots v_c\}$ be the set of c centroids where $x_j \in \Re^m$, $v_i \in \Re^m$, and $v_i \in X$ [10]. It partitions X into c clusters by minimizing the objective function :

$$J_m(\mu, v) = \sum_{k=1}^{N}\sum_{i=1}^{c}(\mu_{ki})^m \, d_{ik}(x_k, v_i) \qquad \ldots(1)$$

where d_{ki} is given by $\|x_i - v_i\|$, c is the number of clusters in X, m is a weighting exponent [6]. The cluster centers are then evaluated by using the following equation:

$$v_i = \frac{\sum_{k=1}^{N}(\mu_{ki})^m \, X_k}{\sum_{k=1}^{N}(\mu_{ki})^m} \qquad \ldots(2)$$

and membership matrix μ is update by the following equation:

$$\mu_{ki} = \left[\sum_{j=1}^{c}\left(\frac{d_{ki}}{d_{kj}}\right)^{\frac{2}{m-1}}\right]^{-1} \qquad \ldots(3)$$

The parameter m is a weighting exponent on each fuzzy membership and determines the amount of fuzziness of resulting classification [13]. And membership value to the data items for the clusters within a range 0 and 1 [16].

3-2 Possibilistic C-Means Algorithm

(PCM) algorithm proposed by krishnapuram and keller [11]. Is based on a modification of the objective function of (FCM). The objective function is:

$$\min\left\{J_m(x,\mu,c)=\sum_{i=1}^{c}\sum_{j=1}^{N}\mu_{ij}^{m}\,d_{ij}^{2}+\sum_{i=1}^{c}\eta_i\sum_{j=1}^{N}\left(1-\mu_{ij}\right)^{m}\right\} \quad \ldots(4)$$

and the membership is updated the following equation :

$$\mu_{ij}=\frac{1}{1+\left(\frac{d_{ij}^{2}}{\eta_i}\right)^{\frac{1}{m-1}}} \quad \ldots(5)$$

Where η_i is the suitable positive number [8].

3-3 Gustafson-Kessel Algorithm

The Gustafson-kessel (GK) is the extension of the fuzzy c-means algorithm. The objective function is:

$$J_q\left(S,\mu,V\right)=\sum_{j=1}^{n}\sum_{i=1}^{c}\left(\mu_{ij}\right)^{q}\,D_{ij}^{2} \quad \ldots(6)$$

Where c and n are the number of clusters and data respectively, μ is a set of membership values μ_{ij}, V is a vector containing the values of clusters v_i, q is the fuzzifier and D_{ij} is the distance. GK used mahalanobis distance.

$$D_{ij}^{2}=\left(S_j-v_i\right)^{T}\,A_i\,\left(S_j-v_i\right) \quad \ldots(7)$$

The A_i is calculated from the following equation:

$$A_i=\left[\rho_i\det\left(F_i\right)^{\frac{1}{n}}\,F^{-1}\right] \quad \ldots(8)$$

And F_i is calculated as follows:

$$F_i=\frac{\sum_{j=1}^{n}\left(\mu_{ij}\right)^{q}\left(S_j-v_i\right)^{T}\left(S_j-v_i\right)}{\sum_{j=1}^{n}\left(\mu_{ij}\right)^{q}} \quad \ldots(9)$$

Where F_i is the fuzzy covariance matrix and ρ_i the cluster volume which is usually set to 1 [1].

4- Kdd Dataset

(Knowledge Discovery and Data Mining) KDD'99 has been the most widely used data set. The network data is distributed by MIT Lincoln Lab for Defense Advanced Research Projects Agency DARPA The KDD cup 99 dataset includes a set of 41 features derived for each connection and a label which specifies the status of connection records as either normal or specific attack type. These features had all forms

of continuous, discrete, and symbolic. The data set encompasses different attack types grouped into one of four categories[17] :

- Dos (Denial Of Service): making some computing or memory resources too busy so that deny legitimate users access to these.
- Probe: Host and port scans as precursors to other attacks. An a network to gather information or find known vulnerabilities, e.g., portsweep.
- U2R (User to Root): Unauthorized access to local super user (root) privileges using system's susceptibility, e.g., buffer_overflow.
- R2L (Remote to Local): Unauthorized access from a remote machine according to exploit machine's vulnerabilities, e.g., imap.

Total number of connection records in training data set is 10% data (494020) records . And the total number of connection record in testing data set is corrected file (311029) records. Table (1) shows the data set used in training and testing stages that contain from normal and attack connection records [17][2].

Table (1) is described the number of samples kdd data set that used [17]

Data set	Normal	Dos	Probe	U2R	R2L	Total
Corrected kdd	60593	229853	4166	70	16347	311029
10_precent kdd	97277	391458	4107	52	1126	494020

5- Data Preprocessing

Data training and testing was taken from (DARPA). This data consist of symbolic and numeric values, all symbolic values were transformed into numeric values [15]. In this research kdd dataset (10_precent kdd) are used in the training stage and (corrected kdd) in the testing stage which contains 41 features (numeric and symbolic), in this research each symbolic of features such as three types of protocols (tcp, udp, icmp) and 68 type of services and 11 types of flag, takes value from [1..n] and then normalized all input data of 10%kdd data set.

6- Experiments And Results

Two indicators were used to measure the accuracy of the methods: detection rate and false alarm rate. The detection rate (DR) shows the percentage of true intrusions that have been successfully detected. While the false alarm rate is defined as the number of normal instances incorrectly labeled as intrusion by the total number of normal instances [4].

6-1 Experiment 1

- First stage, we applied three fuzzy clustering algorithms FCM, PCM, and GK to 10%kdd data set that contains (494020) records. In the first experiment, we apply these three fuzzy clustering algorithms to classify this data set into 23 classes or clusters, One for normal and the rest classes for the types of attacks { DoS (pod, land, back, Neptune, teardrop, smurf), probe (ipsweep, portsweep, satan, nmap), U2R (buffer _overflow, loadmodule, perl, rootkit), R2L(ftp_write, guess_passwd, imap, multihop, phf, spy, Warezclient, warezmater)}. Table(2) shows the result clustering after training these three fuzzy clustering algorithms. The results of classification rate obtained is 100% to classify data into 23 classes one class for normal behavior and 22 classes for different types of attacks, but these three fuzzy algorithms took different

iterations and different times. (When used HP laptop, Intel(R) core (TM) i3 CPU 2.27 GHZ, and RAM 2 GB).

Table (2). The clustering result after training three fuzzy clustering algorithms FCM, GK, PCM to classify data set into 23 clusters

Amount	Sub type of attack	Samples rate
4	phf	0.000810
107201	neptune	21.699729
3	perl	0.000607
9	loadmodule	0.001822
1020	warezclient	0.206469
231	nmap	0.046759
97277	normal	19.690903
2203	back	0.445933
8	ftp_write	0.001619
21	land	0.004251
264	pod	0.053439
280790	smurf	56.837780
1247	ipsweep	0.252419
30	buffer_overflow	0.006073
7	multihop	0.001417
2	spy	0.000405
1589	satan	0.321647
979	teardrop	0.198170
20	warezmaster	0.004048
12	imap	0.002429
1040	portsweep	0.210518
10	rootkit	0.002024
53	guess_passwd	0.010728

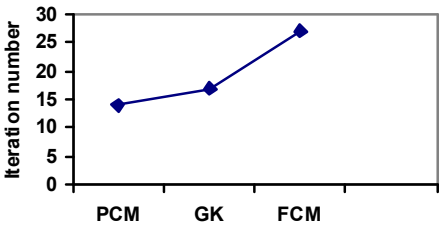
Table (3) shows the result of the first experiment that using FCM, PCM and GK clustering about 23 classes. Whereas Figure (1) shows the relationship between these algorithms and iterations number while Figure(2)shows the relationship between algorithms and time for 23 classes.

As shown in table (3) PCM was classified data set faster than other two algorithms, because PCM takes a number of iterations and time less than other algorithms, but FCM takes a number of iteration greater than GK and PCM algorithms. The classification rate[5] about three fuzzy clustering algorithms was calculated by equation (10):

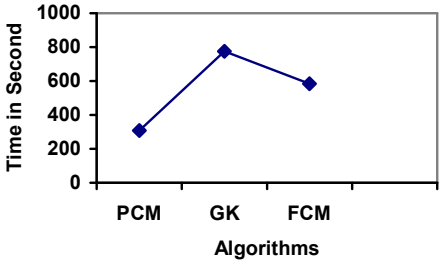
$$classification\_rate = \frac{number\ of\ classified\ patterns}{total\ number\ of\ patterns} \times 100 \quad \ldots(10)$$

Table (3). The result of the FCM, GK, PCM clustering

Type of Clustering algorithms	Fuzzification member	Iteration number	Time second	Classification _rate
FCM	1.2	27	583.8	100%
GK	1.2	17	775.4	100%
PCM	1.2	14	307.5	100%



Figure(1). relationship between algorithms with iterations number



Figure(2). relationship between algorithms with time

- Second stage: "corrected KDD file" data set that contains (311029) records were used in the testing stage on the three fuzzy clustering algorithms FCM, GK, and PCM. Table (4) shows the results of the testing "corrected KDD " file in FCM with detection rate for each attack and normal.

Table (4). results of testing stage of FCM Algorithm

Type	Sub Type	No. of input attacks	No. of detected attacks	DR
Normal		60593	34664	57.208
Dos	apache2	794	794	100
	pod	87	87	100
	smurf	164091	164078	99.991
	back	1098	1098	100
	land	9	9	100
	mailbomb	5000	5000	100
	neptune	58001	58001	100
	processtable	759	759	100
	teardrop	12	0.0	0.0
	udpstorm	2	0.0	0.0
Probe	ipsweep	306	320	95.625
	portsweep	354	0.0	0.0
	saint	736	1090	67.523
	mscan	1053	1053	100
	nmap	84	84	100

	satan	1633	1690	96.627
U2R		70	0.0	0.0
R2L	snmpgetattack	7741	16360	47.317

Table (5) shows the results of testing data by using GK algorithm with the detection rate for each attack and normal behavior.

Table(5). results of testing stage by using GK Algorithm

Type	Sub Type	No. of input attacks	No. of detected attacks	DR
Normal		60593	33418	55.152
Dos	neptune	58001	40372	69.606
	smurf	164091	131134	79.915
Probe	ipsweep	354	252	82.353
U2R		70	0.0	0.0
R2L	snmpgetattack	7741	53043	14.594

and table (6) shows the results testing stage after applying PCM algorithm with the detection rate for each of attack and normal.

Table(6). results of testing stage using PCM

Type	Sub Type	No. of input attacks	No. of detected attacks	DR
Normal		60593	61387	98.707
Dos	pod	87	85	97.701
	smurf	164091	164093	99.999
	land	9	1104	0.815
	mailbomb	5000	4902	98.040
	neptune	58001	40735	70.231
	processtable	759	357	47.299
Probe	saint	736	1398	52.647
	satan	1633	13212	12.364
U2R		70	0.0	0.0
R2L	snmpgetattack	7741	5975	77.238

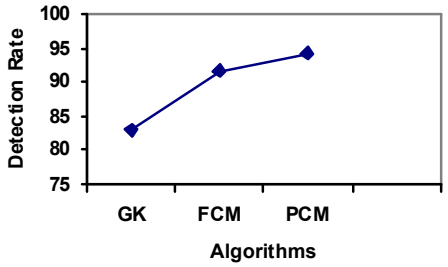
Finally, table (7) shows the comparisons between three fuzzy clustering algorithms FCM, GK and PCM for 23 classes with over all detection rate that obtained for FCM is equal to (91.659) and for GK is equal to (83.021) and detection rate for PCM is equal to (94.284).

Table(7). comparison between FCM, GK and PCM Clustering Algorithm

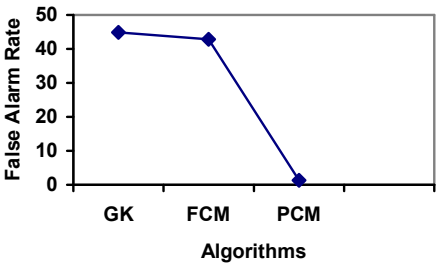
Performance measure	FCM	GK	PCM
Normal detection	34664	33418	61387

Attack detection	250423	224801	231861
Detection rate_normal	57.208	55.152	98.707
Detection rate_attack	99.995	89.764	92.58
False_alarm rate	42.792	44.848	1.310
Detection_rate	91.659	83.021	94.284
Times	13.5 second	28.5 second	14.2 second
Fuzzification member	1.2	1.2	1.2
Iterations	1	1	1

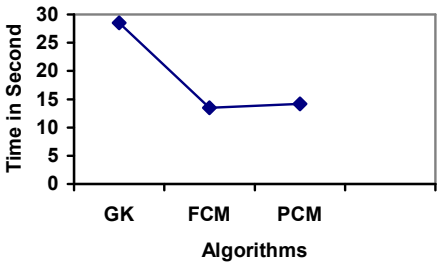
Figures (3, 4, and 5) show the relationship between three clustering algorithms with (Detection rate –false alarm rate – time) respectively.



Figure(3). relationship between algorithms with Detection Rate



Figure(4). relationship between algorithms with False Alarm Rate



Figure(5). relationship between algorithms with time

6-2 Experiment 2

The same data set (494020) records were used after preprocessing it in the training stage to classify it into 5 classes, Table(8) shows the results of experiment for FCM, GK and PCM.

Table (8). The clustering results after training three fuzzy clustering algorithms FCM, GK, PCM to classify data set into 5 clusters

Amount	Type of attack	Samples rate
97277	Normal	19.690903
391458	Dos	79.239302
52	U2R	0.10526
1126	R2L	0.227926
4107	Probe	0.831343

While table (9) shows the results after applying these three fuzzy clustering algorithms FCM, PCM and GK to classify data set into 5 classes. As shown in table (9) PCM was classified data set faster than other two algorithms, because PCM takes a number of iterations and time less than other algorithms, but FCM take a number of iteration greater than GK and PCM algorithms.

Table (9). result of the FCM, GK, PCM clustering

Type of Clustering algorithms	Fuzzification member	Iteration number	Time second	Classification _rate
FCM	1.011	26	134.7	100%
GK	1.011	16	144.5	100%
PCM	1.011	12	67.2	100%

- The second stage of this experiment "corrected KDD file" data set that consists of (311029) records also were used in the testing stage on three fuzzy clustering algorithms FCM, GK, and PCM. Table (10) shows the results of the testing "corrected KDD " file in FCM with detection rate for each attack type and for normal. In which the normal behavior got the higher detection rate is equal (97.813).

Table (10). results of testing stage of FCM Algorithm

Type	No. of input attacks	No. of detected attacks	DR
Normal	60593	61948	97.813
Dos	229853	164611	71.616
Probe	4166	44212	9.428
U2R	70	0.0	0.0
R2L	16347	35795	45.668

After testing data in GK algorithm, the higher detection rate obtained is (98.498) for normal behavior. Which are shown in table (11).

Table(11). results of testing stage by using GK Algorithm

Type	No. of input attacks	No. of detected attacks	DR
Normal	60593	59683	98.498
Dos	229853	171158	74.464
Probe	4166	0.0	0.0
U2R	70	0.0	0.0
R2L	16347	20583	79.4199

Using Possibilistic c-meams (PCM), normal behavior got higher detection rate equals to (99.972) after the testing data set shown in table (12).

Table(12). show results of testing stage using PCM

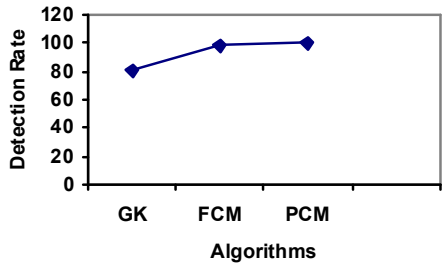
Type	No. of input attacks	No. of detected attacks	DR
Normal	60593	60523	99.972
Dos	229853	164145	71.413
Probe	4166	0.0	0.0
U2R	70	0.0	0.0
R2L	16347	86291	18.944

Finally, table (13) shows the comparisons between three fuzzy clustering algorithms FCM, GK and PCM for 5 classes. with over all detection rate that obtained for FCM is equal to (98.543%) and false alarm equal to (2.236%), while the detection rate that obtained for GK is equal to (80.836%) and false alarm equal to (1.502%), and the detection rate that obtained for PCM is equal to (99.955%) and false alarm equal to (0.116%).

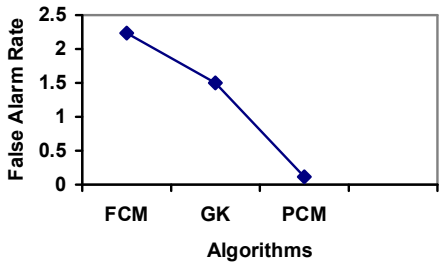
Table(13). comparison between FCM, GK and PCM Clustering Algorithms

Performance measure	FCM	GK	PCM
Normal detection	61948	59683	60523
Attack detection	244548	251424	250366
Detection rate_normal	97.813	98.498	99.884
Detection rate_attack	97.649	76.562	99.972
False_alarm rate	2.236	1.502	0.116
Detection_rate	98.543	80.836	99.955
Times	2.7 second	5.8 second	2.6 second
Fuzzification member	1.011	1.011	1.011
Iterations	1	1	1

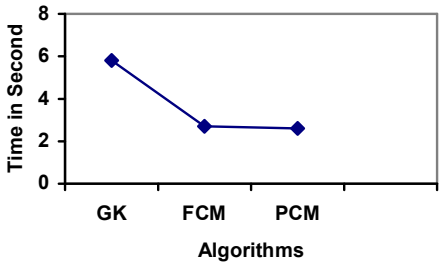
Figures (6, 7, and 8) show the relationship between three clustering algorithms with (Detection rate –false alarm rate – time) respectively.



Figure(6). relationship between algorithms with Detection Rate



Figure(7). relationship between algorithms with False Alarm Rate



Figure(8). relationship between algorithms with time

Finally, table (14) shows the comparisons results of the three fuzzy clustering algorithms FCM , GK and PCM with the previous work .

Table(14). comparison results of FCM, GK, PCM algorithms with previous work

	Algorithm type	Dataset	Normal	Attack	Classification rate%	Detection rate
	FCM[7]	Training (22133)	*	*	99.9	
	Parallel fuzzy ART MAP [14]	Training set	*	*	*	80.14
	Parallel fuzzy ART MAP [14]	Testing set	*	*	*	80.52
First experiment	FCM	Training set	100	100	100	
	FCM	Testing set	57.208	99.995		91.659
	GK	Training set	100	100	100	
	GK	Testing set	55.152	89.764		83.021
	PCM	Training set	100	100	100	
	PCM	Testing set	98.707	92.58		94.284
Second experiment	FCM	Training set	100	100	100	
	FCM	Testing set	97.813	97.649		98.543
	GK	Training set	100	100	100	
	GK	Testing set	98.498	76.563		80.836
	PCM	Training set	100	100	100	
	PCM	Testing set	99.884	99.972		99.955

7- Conclusions

In this research, three fuzzy clustering algorithms were applied to classify intrusion into 23 classes and also classify the same data set into 5 classes, In the first experiment, these three fuzzy clustering algorithms classify 10%kdd data set into 23 classes, one for normal and others for subtypes of attacks and detect these attacks in the first stage of the first experiment by using the fuzzy clustering algorithms FCM, GK and PCM; the classification rate obtained is 100% for these three algorithms. And in the second stage of the first experiment we have got higher detection rate for (PCM) algorithm is equal to (94.284) and less false_alarm rate (1.310). While the (FCM) algorithm got detection rate is equal to (91.659) and false_alarm rate (42.792), and finally, (GK) algorithm got the smaller detection rate (83.021) and higher false_alarm rate(44.848).

In the second experiment, these three fuzzy clustering algorithms classify 10%kdd data set into 5 classes, one for normal and others for types of attacks and detect these attacks. In the first stage of the second experiment, we obtained 100% classification rate for the three fuzzy clustering algorithms FCM, GK and PCM, and in the second stage (PCM) algorithm got higher detection rate (99.955) and less false_alarm rate (0.116). While (FCM) algorithm got on (98.543), but it is got higher false_alarm rate (2.236) and finally, (GK) algorithm has got the smaller detection rate (80.836) and false_alarm rate(1.502). So the results PCM are best performance and next FCM and last GK.

After applying three clustering algorithms (FCM, GK, PCM) on the kdd 99 dataset obtained the following:

- When implement PCM algorithm on this dataset to classify it into 23,5 class, this algorithm got high classification rate (100%) in a few number of iteration and less time compared with the other algorithms.
- Also the PCM algorithm got high detection rate and low false alarm compared with the other algorithms.

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