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Full Length Article

Investigation on IMCP based clustering in LTE-M communication for smart metering applications

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ABSTRACT

Machine to Machine (M2M) is foreseen as an emerging technology for smart metering applications where devices communicate seamlessly for information transfer. The M2M communication makes use of long term evolution (LTE) as its backbone network and it results in long-term evolution for machine type communication (LTE-M) network. As huge number of M2M devices is to be handled by single eNB (evolved Node B), clustering is exploited for efficient processing of the network. This paper investigates the proposed Improved M2M Clustering Process (IMCP) based clustering technique and it is compared with two well-known clustering algorithms, namely, Low Energy Adaptive Clustering Hierarchical (LEACH) and Energy Aware Multihop Multipath Hierarchical (EAMMH) techniques. Further, the IMCP algorithm is analyzed with two-tier and three-tier M2M systems for various mobility conditions. The proposed IMCP algorithm improves the last node death by 63.15% and 51.61% as compared to LEACH and EAMMH, respectively. Further, the average energy of each node in IMCP is increased by 89.85% and 81.15%, as compared to LEACH and EAMMH, respectively.

1. Introduction

Machine-to-Machine (M2M) communication is an evolving technology, which enables many networked devices to communicate with or without human assistance. M2M devices communicate in telemetry language. Here, telemetry means remote machines and sensors transmit data to a central body for analysis [1]. Long Term Evolution for Machine type communication (LTE-M) is an extension of LTE, especially for M2M devices. LTE-M is a unique system developed for M2M communication [2]. In LTE-M uplink, to improve the spectrum and energy efficiency, the LTE-M system makes use of Generalized Frequency Division Multiplexing (GFDM) as an alternative to Single Carrier Frequency Division Multiple Access (SC-FDMA) [9].

The M2M devices are deployed in many fields like smart metering, telehealth, tracking and tracing, remote maintenance and control, manufacturing, facility management and security. The main purpose of this paper is to improve the energy efficiency of M2M devices in smart metering applications [24,21–23]. The smart metering monitors the usage of resources like power, water, gas etc. and sends meter reading to a central body for the purpose of analysis and bill payment [25]. Fig. 1 shows the conceptual schematic of metering devices from each house to evolved Node B (eNB) and then to distribute through control system [10]. According to Fig. 1, '*k*' devices form a group and send aggregated data to eNB. There are about '*n*' devices totally with each group having '*m*' devices. The metering process provides a two-way data transmission between system and meters. It should be noted that the features of M2M communications are different from those of cellular networks. Short packets of data ranging from 10's of bytes to 100 k bytes data are sent during M2M traffic. Here, less importance is given to latency as compared to cellular networks. The LTE-M network is expected as a subset of LTE that can accommodate a huge number of M2M devices at a time. In addition, the M2M Devices conserves low battery life and operates over many years in selected applications. Hence, the data rate in M2M communication is relatively lower as compared to cellular communication [3].

In a real time scenario, M2M devices work on limited supply of battery power as the batteries cannot be replaced. As these devices are considered to be cheap, more focus has to be given for energy efficiency. Hence, the main objective of the paper is to improve the energy efficiency of M2M devices [12]. Once the M2M devices are deployed in the field then the lifetime of battery has to be conserved as the deployed devices coexist with LTE/LTE-M networks [4]. The goal is to reduce the energy consumption of devices with

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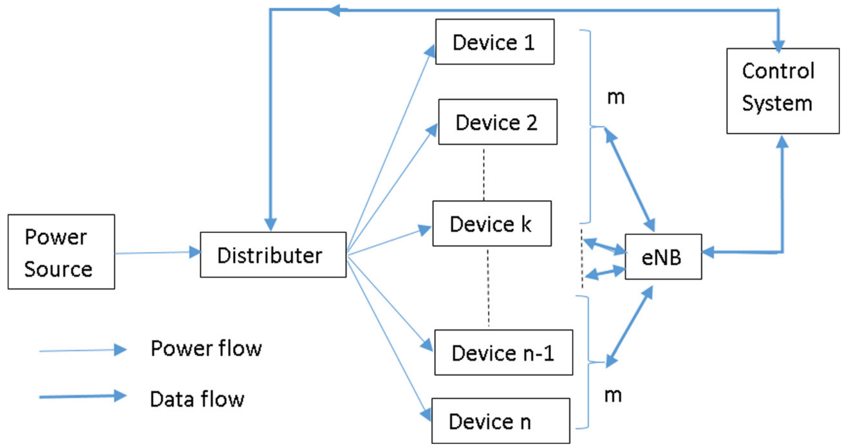

Fig. 1. General flowchart of metering process.

the best Quality of Service (QoS) requirements as it is related to optimal design. Energy efficiency is computed based on bits per second per watt or bits per joule, which defines the throughput of the system per unit energy consumed during uplink transmission. In this paper, we consider energy consumption during transmitting data, circuitry consumptions, wake-up and sleep power consumption. For the system to last longer, we need to design system in such a way that the earlier mentioned parameters should consume the least power with expected QoS.

In LTE-M networks, a large number of M2M devices is deployed in the field with a single eNB controlling them. If all devices start accessing eNB then it will lead to congestion as M2M devices has limited portion of resource blocks from LTE network. Hence, a solution to these problems is clustering, which has proven to be an efficient way to a huge number of devices to communicate. Clustering involves some portion of devices to be as Cluster Heads (CHs) and these CHs form groups with devices called Group Members (GMs). The CH aggregate data from these GMs and after processing, the data's are relayed to eNB. The main part of clustering is it reduces the number of M2M devices accessing eNB, which saves the overall system energy and reduces the number of signal overhead in the network [8]. Wireless sensor network (WSN) are similar to M2M communication in characteristic features to a certain extent. Many clustering algorithms have already been deployed in WSN fields, which can be correlated with clustering in M2M communication. As a number of devices deployed in WSN is less in numbers as compared to M2M devices, the clustering algorithms with WSN is found to be unsuitable for energy saving with M2M scenarios [6]. Hence, this paper aims to suggest an improved M2M clustering process (IMCP) algorithm for embryonic M2M networks.

The reminder of the paper is organized as follows: Section 2 describes the works related to clustering with M2M devices. Section 3 provides the system model that elucidates about the component of the M2M network. Section 4 explains the processes involved in the proposed algorithm for two-tier and three-tier systems. Section 5 gives the performance of the proposed algorithm in M2M networks for various scenarios and network conditions. Section 6 concludes the findings discussed in this paper.

2. Related work

In the research of clustering, Low Energy Adaptive Clustering Hierarchy (LEACH) is the first and foremost algorithm as an energy efficient algorithm [11]. Here, every node has the probability of becoming a CH. Also, CH directly communicates with eNB by interchanging data in a compressed manner, thus conserving energy of the network. CHs have a limit to aggregate data from GMs and in energy. So formerly chosen node's as CH's are not chosen as CH again for a certain period. This way all nodes can become CH's thus reducing energy of the node. LEACH involves two phases: (i) setup phase, where clusters are formed, advertisements by CHs and scheduling of data transmissions carried out and (ii) data aggregation, data compression and transmission. LEACH algorithm has no global knowledge of the network. Energy efficiency is met by reducing communication cost function and keeping a node in sleep mode as much as possible. This algorithm is applicable only to the short-range area as its two-hop model, the node to CH and then from CH to eNB. CHs far away from eNB tend to exhaust very soon than which are near. Within little iteration (rounds), the system seems to consume all system energy, which may be due to non-uniform distribution of CHs with uniform consumption of energy.

Energy-aware multi-hop multi-path hierarchy (EAMMH) [5] is an improvement over LEACH with multi-hop and multipath algorithm. This algorithm also has same two phases as LEACH. Once nodes are randomly deployed CHs are chosen by CH selection mechanisms. CHs form their own GMs by neighbor discovery with fixed size. Each GM in the cluster maintains updated routing table of nodes and process of transmission is same as LEACH. In Lutful Karim et al. [13], an energy efficient and secure clustering mechanism (ESM) is suggested that explains about energy efficiency on selected number of active M2M devices and lightweight based security schemes. Here energy consumption is more compared to other methods in the literature, which due to security issues based on shared key process.

The design in Dusit Niyato et al. [14] targets home energy management system (HEMS), which is capable of optimal and adaptive power generation, consumption and distribution. HEMS systems provide an optimal way of traffic generation with minimal cost. Cognitive M2M communication in Hyun-Kwan Lee et al. [15] solves congestion problems considering service and network fees. Here, network parameters are designed in business and engineering perspective. Hierarchically structured M2M networks are dealt in Ieryung Park et al. [16] to effectively accommodate data from nodes which is then transmitted to cluster-heads. Here, the back-off algorithm is utilized that achieves less average latency with reduced energy consumption per node basis when compared with other well-known MAC protocols. Accordance to Andres Laya et al. [17], the majority of wireless communication will be based on M2M communication and clustering is carried by multiple radio interfaces. Also, cooperative retransmission methodology is employed over the cellular network for short range networks to reduce traffic load and energy consumptions.

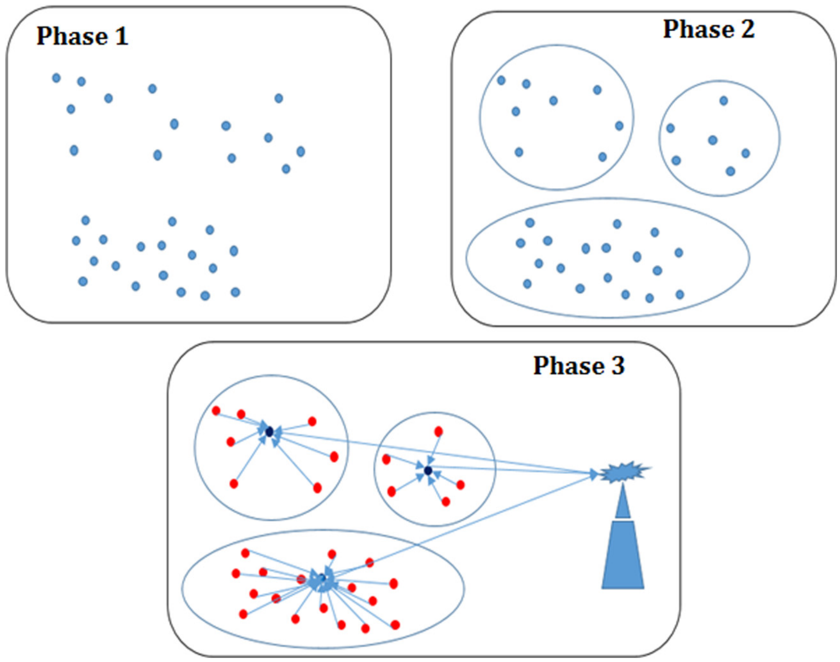

Fig. 2. System model presenting the clustering process involved in two tier system.

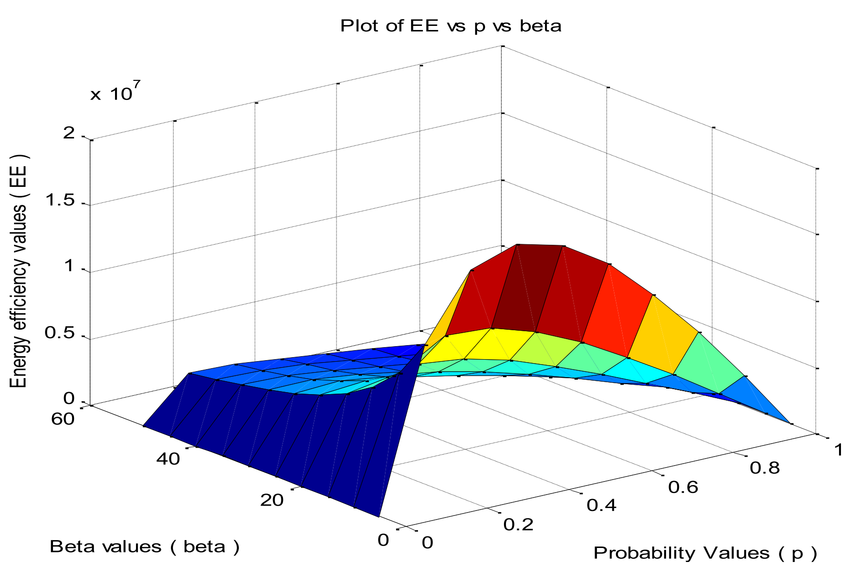

Fig. 3. Plot showing variation of energy efficiency with respect to beta and probability values.

Providing LTE connectivity in emerging M2M communication applications in explained in Antonis et al. [18] with scheduling mechanism which effectively routes M2M traffic. Quality of Service (QoS) performance is analyzed with fixed scheduling algorithm, and then few modifications are done to explore dynamics in queuing when nodes are grouped into clusters. In Shih-En et al. [19], clustering is considered as a key method to support a large number of M2M communicating nodes. Certain scenarios are implemented where clusters may reuse spectrum which is used by human devices through certain power control. Data rate constraints of M2M and human devices are formulated by mixed integer non-linear programming (MINLP).

An improved energy saving methodology is implemented in Linlin et al. [20] for M2M communication in LTE based system). Phase one is clustering to minimize energy consumption and the second phase is resource allocation. Clustering based resource allocation reduces the random access blocking and largely minimizes signaling consumption. Alternatively, Smart metering scenario is implemented over 2G/3G network explaining problems like spectrum shortage in dense areas and low coverage issues. Recently, energy efficient clustering in mobility-centric node scheduling has been proposed for M2M communication networks [26,27]. Here, the scheduling scheme aims to extend coverage by selecting a limited number of M2M devices in an active state and improve fault tolerance by different selection of cluster heads and member nodes.

3. System model

The assumptions of the system model is as follows: (i) Devices are homogeneously distributed in the cell with definite radio range

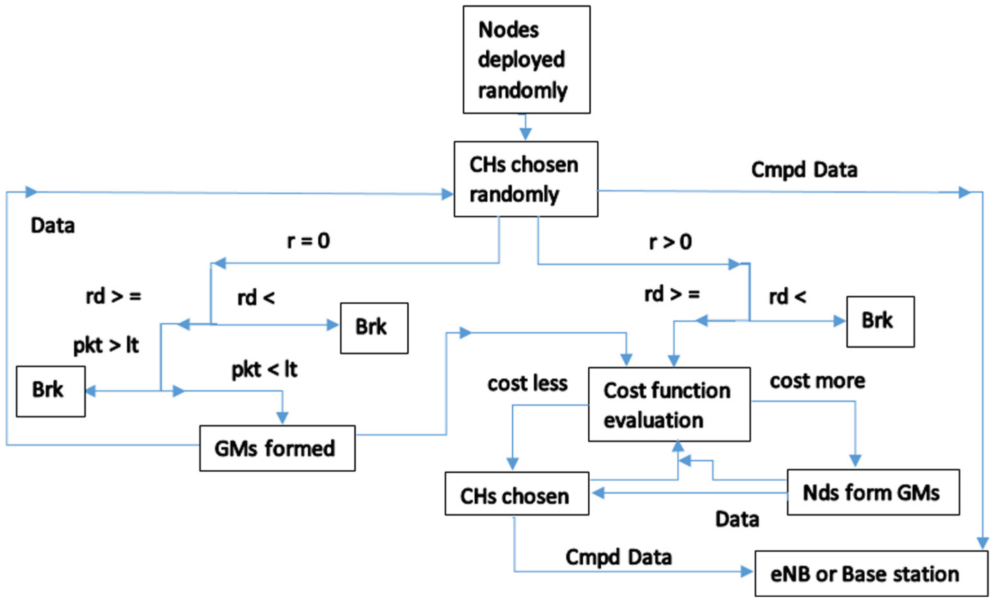

Fig. 4. Chart of the proposed clustering process involved in M2M communication.

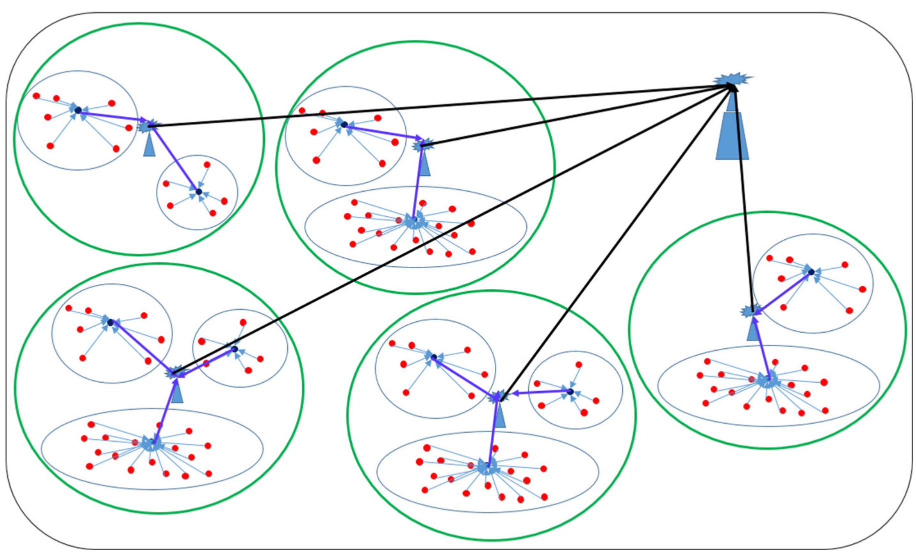

Fig. 5. System model presenting the process involved in three-tier M2M system.

(ii) Short distances called intra-communication is from GM to CH, and long distances called inter-communication is from CH to eNB, are considered for propagation of data packets, (iii) Each device communicates in an isotropic propagation manner selecting nearest node which is CH for intra communication, (iv) eNB is considered outside the field region (v) System bandwidth is assumed to be evenly distributed among each CH. The system model is illustrated in Fig. 2.

The system model in two-tier system involves:

1. Randomly deploying M2M devices in the field.
2. Clustering of devices appropriately.
3. Forming cluster head (CH) and relaying data.
4. Processing data in CHs and then sent to eNB.

To build the system efficiently, we need to find the optimal value of p (percentage of nodes to become CHs) from system's total data rate $R_{sys}(p)$ and system's total power consumption $P_{sys}(p)$. Hence, the energy efficiency (*EE*) is given as follows:

$$EE(p) = \frac{R_{sys}(p)}{P_{sys}(p)} \quad (1)$$

In real-time scenario, the M2M devices may be in the corner of the field. In order to consider the shadowing loss (Z) and path loss models (*PL*), we refer Peng [6] to the intra communication cost like short distance path-loss model (PL(a)) with shadowing effect (Z_a), where GMs transmit data to CH's at a distance of D2. Similarly, for long distance path-loss model (PL(e)) with shadowing effect (Z_e), CHs transmit data to eNB at a distance of D1.

$$PL(e) = 128.1 + 37.6\log(D1/1000) \quad (2)$$

$$PL(a) = 28.5 + 20\log(D2) \quad (3)$$

The transmit power of GM is denoted as (P_t(GM)) and transmit power of CH is given by (P_t(CH)), where $P_t(CH) = \beta P_t(GM)$ with β being power ratio to calculate reach power of GM (P_j(GM)) and CH (P_k(CH)), respectively. Here, *j* refers to *jth* GM and *k* is *kth* CH.

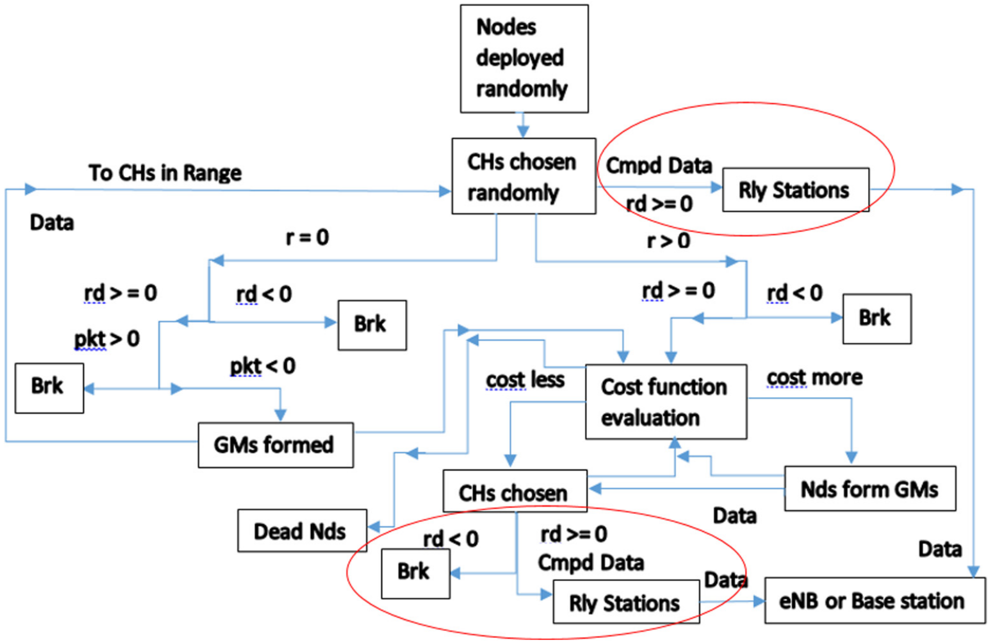

Fig. 6. Chart of the proposed clustering process involved in M2M communication for three tier systems.

Table 1
Simulation parameter for M2M smart metering application.

Description	Values
Dimensions of field ($X_f \times Y_f$)	800×800
Range of nodes (m)	40
BS coordinate	$0.5 * X_f$ and $0.5 * Y_f$
Number of M2M nodes in the field	6000
Maximum number of rounds	100
Probability of number of CHs	0.172
Intra and inter shadowing (dB)	1.9953 and 3.9811
System bandwidth (Hz)	$20 * 10^6$
Cluster bandwidth (Hz)	$200 * 10^3$
GM transmit power (W)	0.01
Circuit power losses (W)	0.0032
Thermal noise power (W)	$4 * 10^{-21}$
Sleep power (W)	$15 * 10^{-6}$
Wake power (W)	0.0135
Cell radius (m)	800
Packet size (bytes)	16,136
Power ratio	30
Cost power	5
Energy of each device (J)	0.5
Each Round (Iterations)	10,000

$$P_j(GM) = P_t(GM) * 10^{\frac{-(PL(a)+Za)}{10}} \tag{4}$$

$$P_k(CH) = \beta P_t(GM) * 10^{\frac{-(PL(e)+Zb)}{10}} \tag{5}$$

By using Eqs. (4) and (5) and Shannon capacity equation, the data rate of each GM and CH is written as:

$$R_j(GM) = \left(\frac{w_2}{Mk+1}\right) \log\left(1 + \frac{P_j(GM)}{N_o \frac{w2}{M_k+1}}\right) \tag{6}$$

$$R_k(CH) = \left(\frac{w1}{np}\right) \log\left(1 + \frac{P_k(CH)}{N_o \frac{w1}{np}}\right) \tag{7}$$

Here, w1 and w2 are bandwidths of system and cluster respectively. The 'n' is a number of M2M devices in the field with 'np' number of CH selected from them. M_K is the number of GMs for each Kth CH. $(w2/(M_K+1))$ is the bandwidth allocated to each member in the cluster. Considering circuit power consumption P_{ckt} whole power consumption of GM and CH are as follows:

$$P_0(GM) = P_{ckt} + P_t(GM) \tag{8}$$

$$P_0(CH) = P_{ckt} + P_t(CH) \tag{9}$$

As we know number of CHs and GMs in the field, the total system power consumption is given by

$$P_{sys}(p) = npP_0(\mathrm{CH}) + n(1-p)P_0(\mathrm{GM}) \tag{10}$$

Similarly, total system data rate follows:

$$R_{sys}(p) = \sum_{j=1}^{n(1-p)} R_j(\mathrm{GM}) + \sum_{k=1}^{np} R_k(\mathrm{CH}) \tag{11}$$

where R_{sys} is the total system data rate with optimal value of p. The Eqs. (10) and (11) are used in Eq. (1) to find out system energy efficiency equation.

From Eqs. (10) and (11) we know that date-rate depends on bandwidth (BW) and location of nodes. The expected value of energy efficiency is given by:

$$E(EE(p)) = \frac{w1 \log(1+pA)}{\lambda \pi R_c^2 (C+pD)} + \frac{w_2(p-p^2)\log\left(1+\frac{B}{p}\right)}{C+pD} \tag{12}$$

where,

$$A = \frac{\beta P_t(GM)\lambda\pi R_c^2}{29.3695(\mathrm{N_o w_1 R_c^{3.76}})}, \quad B = \frac{\lambda P_t(GM)}{3531.4 * N_o w_2},$$

$$C = (P_t(GM) + P_{ckt}), D = (\beta - 1)P_t(GM)$$

From Eq. (12) we can obtain the optimal value of p with a maximum value of energy efficiency for different value of β.

4. Improved M2M clustering process (IMCP)

As β value increases, we can observe that EE value decreases as shown in Fig. 3. From Eq. (12) we can see that as β value increases A and D value also increases. But the increase in A value means an increase in data rate and an increase in D value means an increase

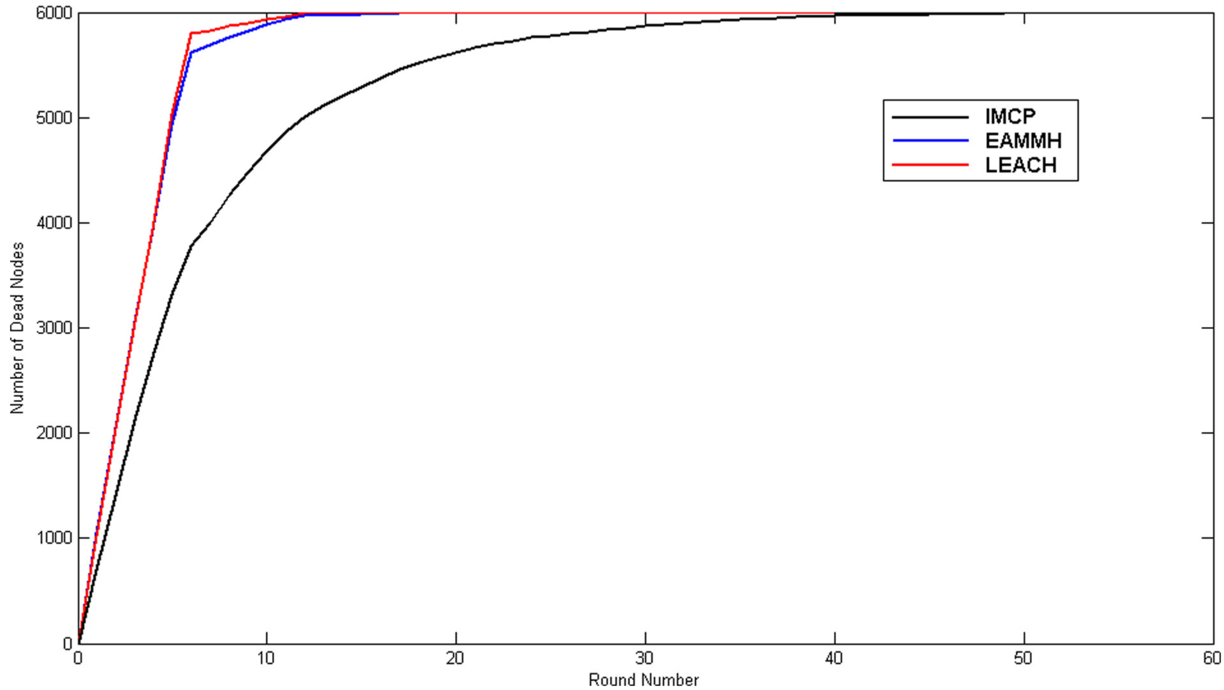

Fig. 7. Number of dead nodes for LEACH, EAMMH and IMCP.

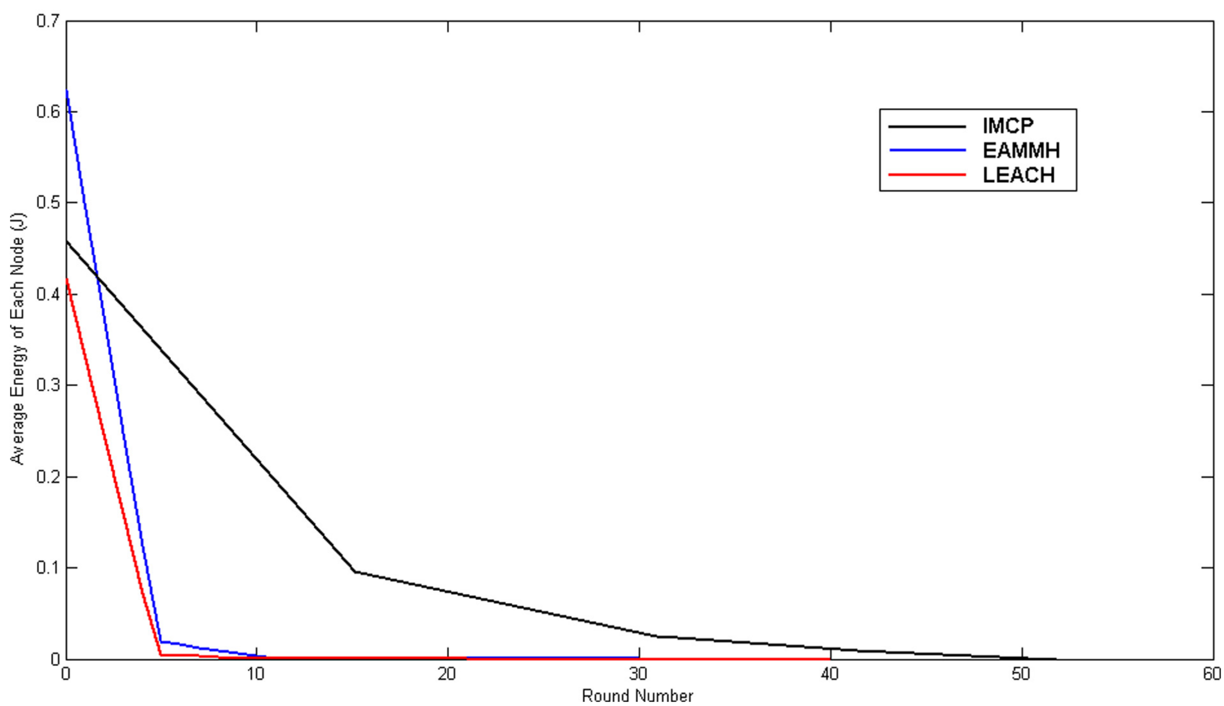

Fig. 8. Average energy of nodes for LEACH, EAMMH and IMCP.

in power consumption of the system. Hence, appropriate value of β needs to be chosen for the optimal working of the system. Fig. 3 also describes that for the higher value of β we get lower p. Therefore, by increasing power consumption of devices increases the data rate of the system, but will soon lead to exhaustion of the system power. So by choosing the certain value of β we obtain optimal value of p which leads to an optimal number of CH so that system remains in working state for a long time. Similarly, we can find for different value of β different curves and optimal p values. For the proposed IMCP algorithm we choose $\beta = 30$ for which we get $p = 0.172$.

Previously we have calculated the optimal number of CH (np). But for simulation purpose, we don't activate all CHs at a time. From np number of CH we choose which CH to be next based on communication cost function. There are two types of communication cost functions: (i) intra communication cost, (ii) inter communication cost. Depending on the number of CHs and bandwidths of system and cluster allotted we choose that many numbers of CHs

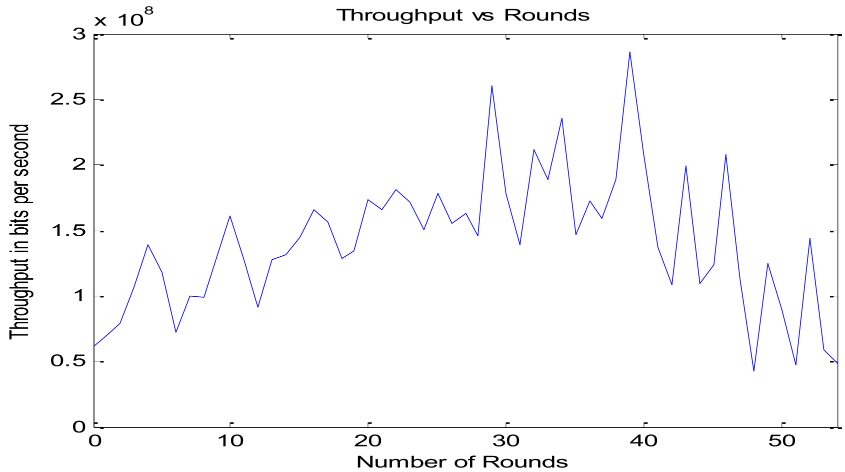

Fig. 9. Throughput in each round of new algorithm, IMCP.

at a time. During first round randomly np number of CH are chosen, out of which depending on BWs of system and cluster, the number of CHs are selected at a time per sub-round. So in first round number of sub-rounds depend on np and BWs of system and cluster. From second round onwards depending on cost functions only CHs are chosen. So second round starts with CH reselection part as the residual energy of nodes also need to be considered. Consider inter-communication cost (F_i) [6], which is from CH to eNB, of every GM of a cluster. Here we assume all CH have same transmission power P_t and different reach power P_k depending on long distance path-loss model.

$$F_i = \frac{(M_K+1)D_i^{3.76}}{\sum_{j=1}^{M_K+1} D_j^{3.76}} \tag{13}$$

where D is the distance from GM position to eNB. i and j are current chosen node and all node's index respectively. M_K is a number of GMs in a cluster. Similarly in intra-communication cost (f_i) function transmission power of GMs are same but reach power depends on short distance path loss model. Similar to previous equation

$$F_i = \frac{(M_K+1)\sum_{j=1}^{M_{K+1}} D_{ij}^2}{\sum_{k=1}^{M_K+1}\sum_{j=1}^{M_{K+1}} D_{kj}^2} \tag{14}$$

D is distance from GM to CH. Considering the indices ij is to indicate i as currently chosen CH and j being other unselected GMs, kj is to indicate k as temporarily chosen GM as CH and j being other unselected GMs.

In CH reselection part, the consideration of residual energy is of great importance [7]. To conserve energy, the node should be wake state while transmitting data and in sleep state during inactive data transmission. Considering wake-up time to be $t_{gmw} = l/R_j(GM)$, where l is packet length and $R_j(GM)$ is data rate of GM. Hence, calculating the energy consumption of GM j in time T hours is:

$$C_j(GM) = \frac{T}{t_o}(P_0(GM)t_{gmw} + P_w t_{gmw} + P_s(t_o - t_{gmw})) \tag{15}$$

where P_w and P_s are wake and sleep power consumptions, t_0 is device time interval between two events. Similarly, energy consumption of CH is:

$$C_k(CH) = \frac{T}{t_o}(P_0(CH)t_{chw} + P_w t_{chw} + P_s(t_o - t_{chw})) \tag{16}$$

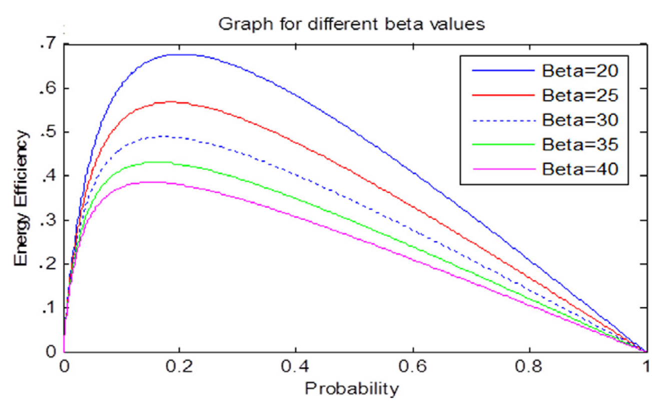

Fig. 10. Energy efficiency values for different beta values in IMCP.

where $t_{chw} = (\alpha(M_K + 1)l/R_K(CH))$ is CH wake-up time, α is aggregation parameter of CH. Depending on application aggregation parameter value is chosen.

Therefore total system energy consumption is:

$$C_{sys} = \sum_{k=1}^{np}\left(C_k(CH) + \sum_{j=1}^{M_k} C_{kj}(GM)\right) \tag{17}$$

Eqs. (15) and (16) define devices energy consumption. Consumption of devices can be calculated after T hours. After normalizing consumption E_i is:

$$E_i = \frac{(M_K+1)E_i}{\sum_{j=1}^{M_K+1} E_j} \tag{18}$$

Now the cost function is the combination of Eqs. (16)(18):

$$\cos t_i = sum(f_i, F_i, wE_i) \tag{19}$$

where w is cost parameter and $cos\ t_i$ decides which node will become CH next. Here, the minimum value of cost function will contribute the CH index to choose.

The process of clustering in M2M communication is shown in Fig. 4. It starts with the deploying of nodes in the field. From the randomly deployed nodes, CHs are chosen as it's in the homogeneous stage. As all nodes are entirely charged, nodes are not chosen with respect to energy. After the first round, all chosen CHs have lost some energy which brings it to the heterogeneous stage. In

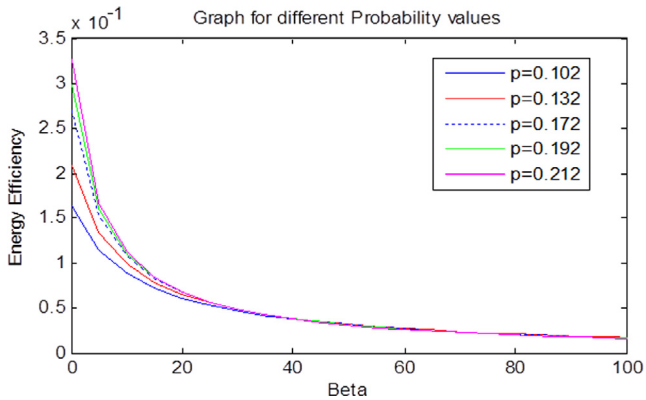

Fig. 11. Energy efficiency values for different p values in IMCP.

the first round if nodes are there in the range of CH, then those nodes form GMs of CHs. After acquiring packets from GMs, the data is collected, compressed and transmitted to eNB. From second round onwards similar conditions are followed, the only difference is this time CHs are chosen based on a cost function for every sub-round. Here, cost function according to Eq. (19) should be minimum for an indexed node to be next CH. If cost function is more, the loop continues from GMs onwards again to get the minimum cost of them. The algorithm continues until all nodes are dead or they are all out of energy.

4.1. IMCP algorithm with mobility for three tier system

The tremendous increase in M2M devices has lead research to come up with optimal resource allocation and scheduling strategies for better performance of the network. In addition, it is difficult for the M2M devices to access the eNB with reduced access delay. In order reduce the delay load of the M2M devices has to be balanced with reduced energy consumption. In three tier M2M system, a relay node placed for collecting data from various M2M nodes. Its main purpose is to collect data from CHs, amplify them and relay them to eNB. In three tier system, data is aggregated from GMs and transferred to respective CHs and then to eNB as shown in Fig. 5.

The flowchart of the three tier relay system is shown in Fig. 6. As we compare between two and three tier systems, only difference we see is the relay station block diagram. CHs which are in the range of relay station become cluster head members (CHM). In this work, the range of relay station is considered three times that of CH. A number of relay stations are selected from the chosen CHs. Also, these relay stations will not be acting as sensing agents from surroundings. Its main part is to collect data from CHs and transmit it to eNB. Number of relay stations to be elected is done using energy efficiency equation as was done with two tier system. By this analysis number of relay stations elected are 270, as the number of CHs elected are 1032 and from this p value we got is 0.2623.

5. Performance evaluation

The performance of M2M communication with clustering algorithms, namely, LEACH, EAMMH and IMCP is carried out in MATLAB 2015 and the parameters used in the simulation is shown in Table 1 [6]. Fig. 7 displays the number of dead nodes according to LEACH, EAMMH and IMCP algorithms. From the curves in Fig. 7, although EAMMH shows improvement in the number of dead nodes over few rounds than LEACH, it converges to the latter when the round becomes fifteen. The reason for this may be due to inadequate knowledge of network for LEACH and not the proper distribution of CH in the field for EAMMH. In both of these algorithms, there is no optimal value of p being considered, with inadequate parameters, such as cost function and energy saving parameters. This result in the low energy of each node as shown in Fig. 8, where the average energy of each node sinks to zero soon after ten iterations. From the curves, we could infer that IMCP method shows far better results than LEACH and EAMMH algorithm.

In IMCP, nodes last up to forty rounds that are four times better than the existing algorithms. In addition, the average energy in IMCP last up to 50 iterations which is five times better than the existing algorithms. Here, each round is carried out for eleven sub-rounds. Hence, with IMCP not all nodes will die up to four

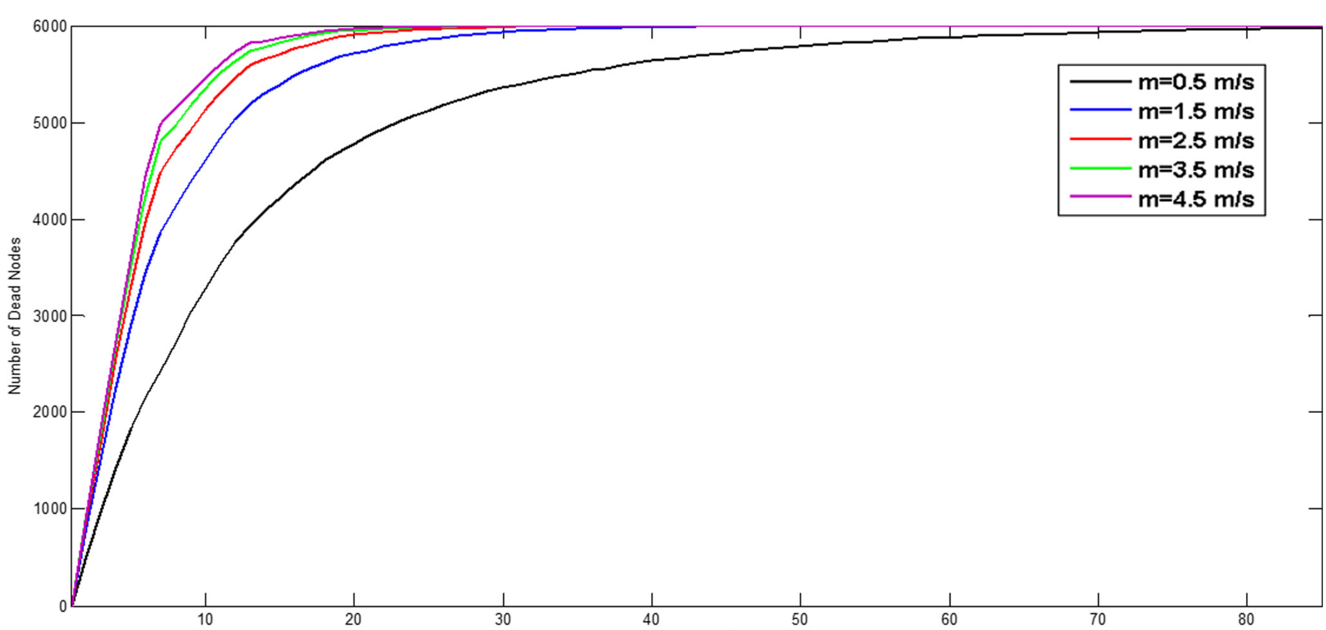

Fig. 12. Number of dead nodes for different values of mobility for IMCP algorithm.

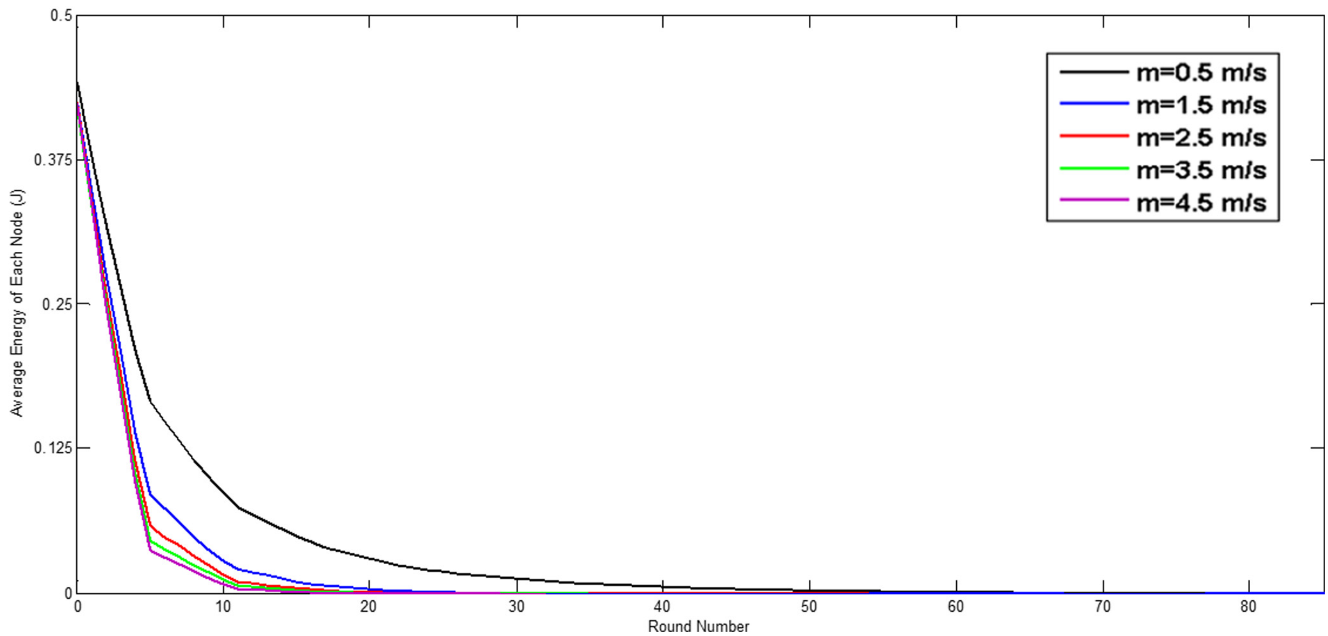

Fig. 13. Average energy of nodes for IMCP with varying mobility speeds.

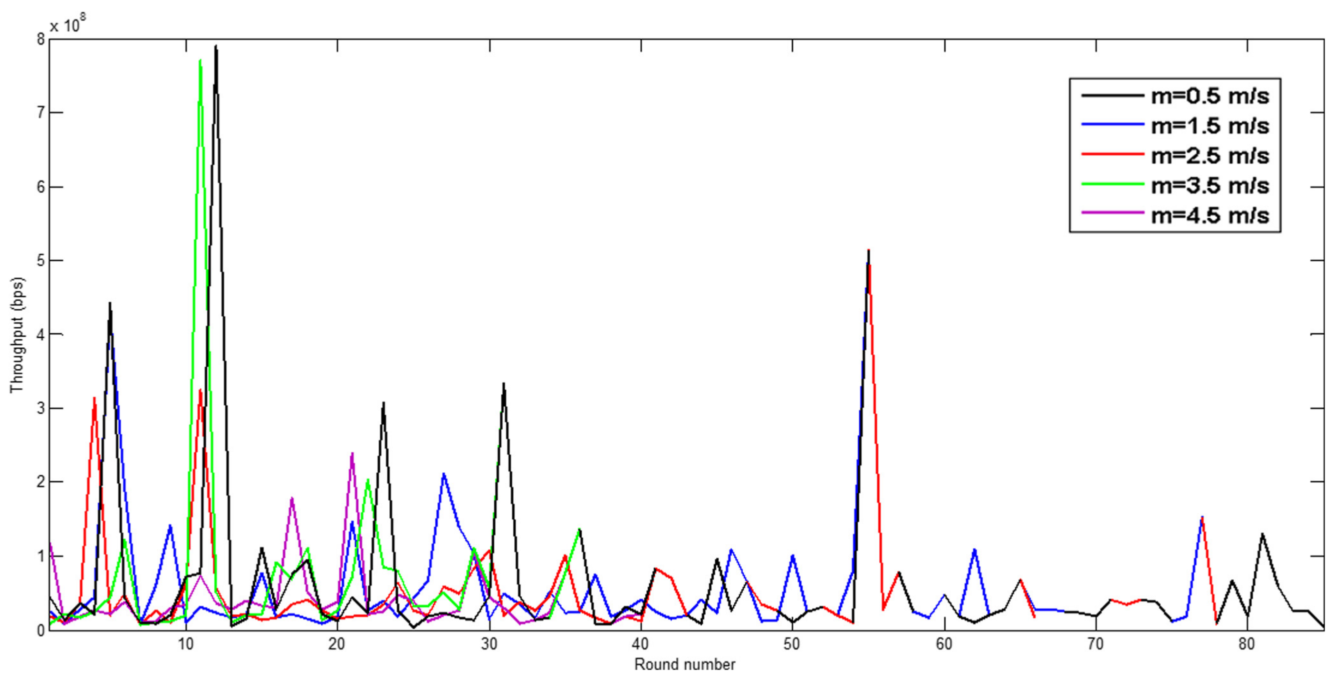

Fig. 14. Throughput of system for IMCP process for two tier system with mobility parameter.

hundred forty rounds, and the average energy of each node in IMCP will last up to five hundred fifty rounds totally. Although currently implemented IMCP is better than LEACH and EAMMH, IMCP can still be made better by a dynamic method where p and beta can be varied to meet certain expectation in certain regions on the field. When CHs are aggregating less number of devices then their limits, the IMCP doesn't consider devices which are out of range and it has no CH to attach. However, CHs at the boundaries of the field may attach to less number of devices than its limits, and such CH should be made use for attaching with nodes which are in range of no other devices. Fig. 8 displays the energy efficiency according to LEACH, EAMMH and IMCP algorithms. According to IMCP, each round consists of ten sub-rounds and in each sub-round hundred CHs are activated (i.e., hundred clusters) to collect data from their GMs in two-tier system.

Although we have discussed energy efficiency on beta, p, dead nodes and lifetime measurements, throughput has to be analyzed to evaluate the network utilization with an increase in the number of rounds as shown in Fig. 9. We can see many variations in throughput values, which is due to the distance of CHs, data rates and transmission delays. A maximum throughput of 280 Mbps and an average throughput of 150 Mbps can be inferred from the curves. Fig. 10 shows the graph for energy efficiency versus probability with different values of beta. For diverse beta values

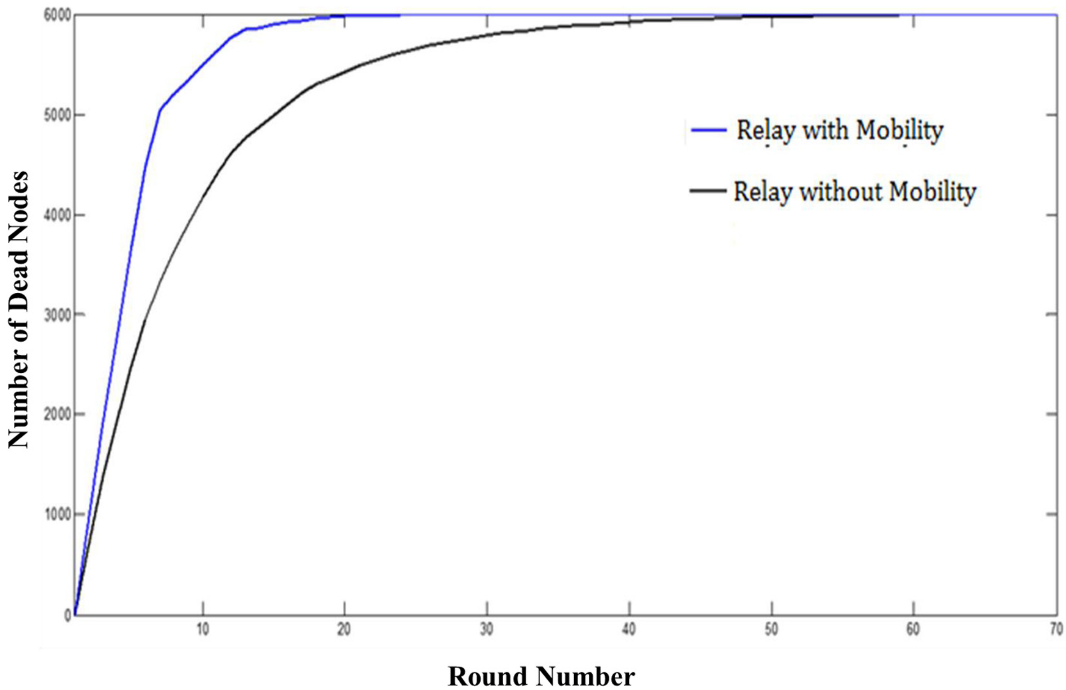

Fig. 15. Number of dead nodes for IMCP process for three tier system (with relay (rly)).

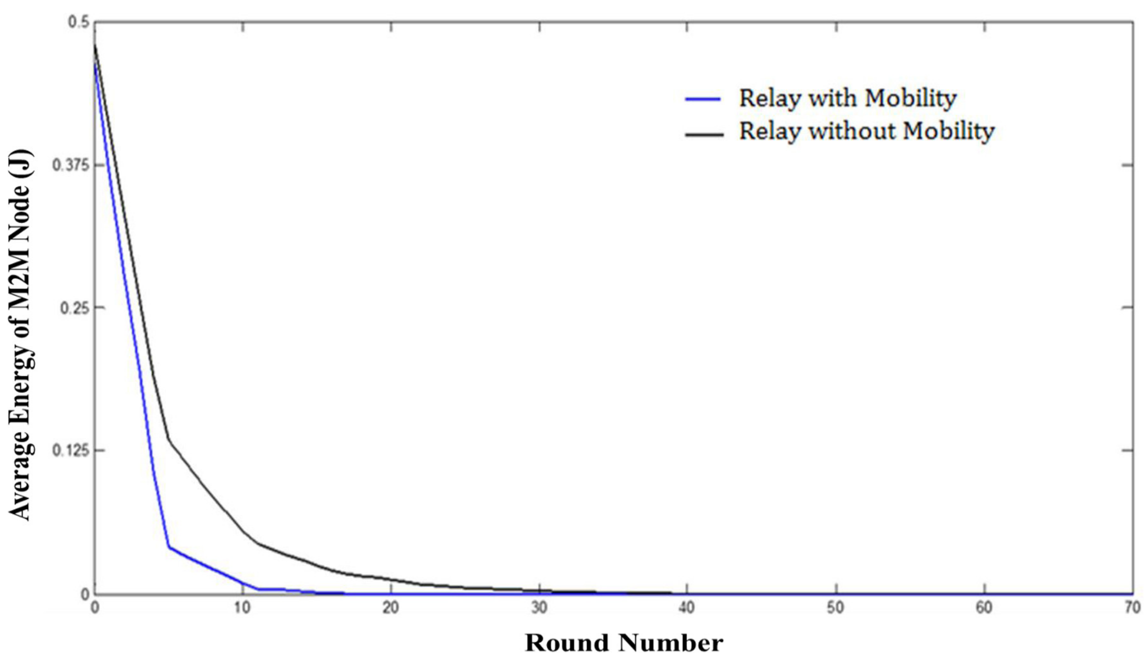

Fig. 16. Average energy of nodes for IMCP process for three tier system (with relay (rly)).

different optimal p values are drawn, but from practical point, suitable beta value should be considered for long networking life. Although different beta values come into existence, it leads to different transmission values of CHs and also different aggregation factor. From the curves, one could infer that the large beta value will drain more network energy and lifetime of the nodes. Similarly, Fig. 11 shows energy efficiency curve with an increase in beta values for various values of 'p' and this decides the number of CHs and the aggregation factor. However, manual setting of 'p' may not be a very good choice as it may not coordinate well with the practical system, which leads to variation in aggregation factor.

5.1. IMCP algorithm with mobility for two-tier system

One important issue in implementing mobile CH nodes in M2M network is how the CH gathers data from static M2M nodes while CH is moving. As the CH is moving the location of the CH changes, therefore M2M nodes can only send the data packages to the CH when CH is in their range. Therefore traditional data gathering and routing schemes are not suitable in this case. The M2M nodes have limited source of energy when it is deployed in real time environment. The entire network relies on this energy to detect an event, collect information from the environment, data aggregation

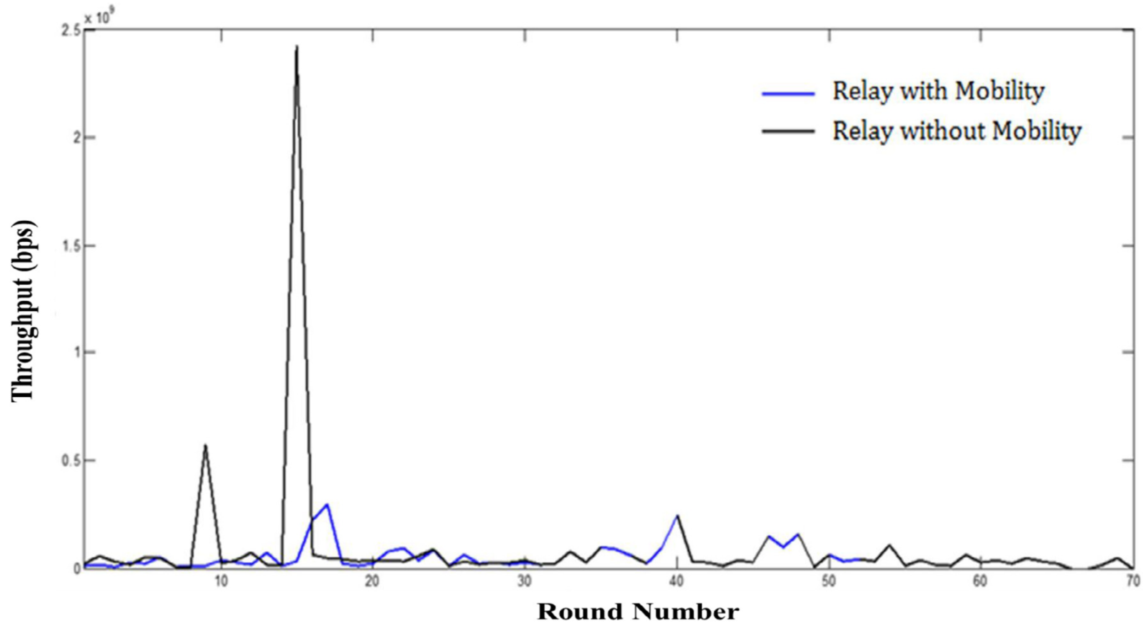

Fig. 17. Throughput (bps) for IMCP process for three tier system considering with and without mobility parameter.

Table 2
Comparison of LEACH, EAMMH and IMCP algorithms with respect to number of rounds and max throughput.

Clustering Algorithms	Rounds after which all nodes die (Rounds)	Throughput after 5 rounds (bps)	Energy after 5 rounds (J)
LEACH	12	0.25×10^6	0.035
EAMMH	15	1.35×10^6	0.065
SEP-E [28]	19	4.5×10^6	0.115
IMCP (Two-tier without Mobility)	31	3×10^8	0.345
IMCP (Two-tier with Mobility)	26	7.8×10^8	0.295
IMCP (Three-tier without Mobility)	39	2.3×10^9	0.415
IMCP (Three-tier with Mobility)	25	0.7×10^9	0.215

Note: Each round corresponds to 10,000 iterations.

and communicate with a base station or CH to deliver the collected information. The main challenge is to maximize the network lifetime using minimum energy resource.

Fig. 12 shows a number of dead nodes with mobility parameter ranging from 0.5 m/s to 4.5 m/s for two-tier system. As the mobility parameter increases, the number of dead nodes increases. Such characteristics is due to more energy consumption due to movement, which effects on a lifetime of the node. CH not only moves around but also responsible for relaying data from GMs to eNB, which also includes computational complexity involved in data compression. Fig. 13 shows the average energy of nodes for each round for two-tier system. As seen in the curves, high mobility lowers the energy of the nodes. The rapid death of the nodes is preserved by considering the mobility of CH that move towards the node that has the least energy in the group so that energy of nodes is conserved.

The throughput of M2M system with IMCP is shown in Fig. 14. The curve shows a peak throughput at 12th round for mobility of 0.5 m/s. As seen from the curves, although the throughput of the M2M network reduces with increase in the mobility speed, the reduction in throughout is less significant due to cooperative means of transmission between the nodes with IMCP. Hence, the proposed means of M2M node deployment improves the network performance under moderate mobility. Figs. 15–17 shows the number of dead nodes, the average energy of the node and throughput of the M2M nodes for IMCP method for three tier systems operating with and without mobile relay stations. For instance, with round number 7, the number of dead nodes under relay mobility is 63.2% more than the three-tier network without relay mobility. Also, the average energy of each node without relay mobility is reduced by 43.6% than the node under relay mobility. Hence, the throughput of the node is increased by 58% in M2M based network without relay mobility than the network with relay mobility. As mentioned earlier, although the node mobility does not provide any performance reduction, the relay mobility provides significant impact over the M2M network.

Table 2 shows a number of rounds for which all nodes die, maximum throughput and energy after five rounds. From the table, it can be observed that IMCP algorithm is far more efficient than LEACH, EAMMH and SEP-E (Stable Election Protocol-Enhanced) [28]. In LEACH nodes die after 12 rounds and in EAMMH it dies after 15 rounds. For instance, with five rounds (50,000 iterations), the average energy of each node in IMCP is increased by 89.85%, 81.15% and 66.67%, as compared to LEACH, EAMMH and SEP-E, respectively. Such performance is due to the reduced number of dead nodes by 63.15%, 51.61% and 38.70% in IMCP as compared to LEACH, EAMMH and SEP-E, respectively. Further, this conservation in the energy of nodes improves the throughput of the M2M network with IMCP by 300 Mbps. However, the throughput is in the order of 100 of kbps in the existing systems. The throughput is further increased by 86.95% in IMCP with the three-tier network as compared to IMCP with the two-tier network. This improvement in throughput is due to the 20.51% less number of node death with 16.86% less energy consumption in the relay based network (three-tier) as compared to the two-tier network.

6. Conclusion and future work

In this paper, an IMCP based clustering in LTE-based M2M communication for smart metering has been investigated for two-tier network and relay based three-tier network. The IMCP based three-tier system under immobile conditions exhibits significant performance improvement in terms of the number of dead nodes, throughput and remaining energy towards the increase in the number of rounds as compared to a two-tier system with no mobility. The performance improvement in the three-tier system is due to the appropriate consideration of relay in IMCP that effectively acquires data from CHs. However, under mobility conditions, the IMCP with two-tier scenario exhibit improved network performance than three-tier framework as there is packet loss while relaying the packets to CH and relay stations. Hence, future work will be based on dynamic highly mobile M2M communication, which includes more computational complexity with adaptive topological conditions.

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