PAPER *Special Section on Cooperative Communications for Cellular Networks*

An Adaptive Weighted Clustering Algorithm for Cooperative Communications

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SUMMARY The cooperative relay network exploits the space diversity gain by allowing cooperation among users to improve transmission quality. It is an important issue to identify the cluster-head (or relay node) and its members who are to cooperate. The cluster-head consumes more battery power than an ordinary node since it has extra responsibilities, i.e., ensuring the cooperation of its members' transmissions; thereby the cluster-head has a lower throughput than the average. Since users are joining or departing the clusters from time to time, the network topology is changing and the network may not be stable. How to balance the fairness among users and the network stability is a very interesting topic. This paper proposes an adaptive weighted clustering algorithm (AWCA), in which the weight factors are introduced to adaptively control both the stability and fairness according to the number of arrival users. It is shown that when the number of arrival users is large, AWCA has the life time longer than FWCA and similar to SWCA and that when the number of arrival users is small, AWCA provides fairness higher than SWCA and close to FWCA.

key words: *cooperative communications, clustering algorithm, WCA, stability, fairness*

1. Introduction

In a cooperative relay network, different users (source nodes) share their resources to improve the transmission quality [1], [2]. A user who experiences a deep fading in its link towards the destination can utilize good channels provided by its relay nodes to achieve the desired quality of service (QoS). As the nodes are distributed in the network, the concept of partitioning the geographical region into clusters has been presented in [1]. A relay node with good condition (i.e., low mobility) is preferred to be a cluster-head. After selecting a suitable node as a cluster-head, its member-relay nodes are selected.

There are three well-known clustering algorithms [2]–[11]: the Lowest-ID heuristic algorithm, the Highest-degree heuristic algorithm and weighted clustering algorithm (WCA). The Lowest-ID algorithm may lead to high battery power consumption of cluster-heads, producing shorter life time of the clusters. While Highest-degree algorithm achieves a low updating rate of cluster-heads, but provides low throughput. The most popular clustering algorithm is WCA.

It is necessary to keep the topology stable as long as possible [12]–[14]. The stability is one of the most important factors. However, the WCA pays little attention to the stability of the network. With the association and dissociation of nodes into/from the clusters, the stability of the network topology is perturbed and the reconfiguration of the network becomes unavoidable. In [15], to improve the stability of the network, we proposed a stability weighted clustering algorithm (SWCA), which takes into account the mobility of the network (the relative speed of a pair of nodes in the network).

The fairness is another critical factor [16]–[19]. The cluster-head spends its energy to serve its members as well as to serve itself; therefore, if a user acts as a cluster-head, its throughput is lower than its member nodes. This is not fair in terms of throughput. In [20], we proposed a fairness weighted clustering algorithm (FWCA). FWCA achieves a much higher fairness than SWCA. However, the higher fairness can be achieved at the expense of lower stability. There is a tradeoff relationship between the stability and the fairness.

Note that in all the above papers, the constant number of arrival users is assumed. In fact, this assumption is not practical, since the users access the network independently. The weighted factors must be adaptively set according to the number of arrival users. When the number of arrival users is small, the fairness is more important than the stability since the cost of network reconfiguration is low. However, as the number of arrival users increases, the network must be stable as long as possible to reduce the cost of network reconfiguration. This paper proposes a new adaptive weighted clustering algorithm (AWCA) which takes into account both the stability and the fairness.

The remainder of this paper is organized as follows. Section 2 overviews the previous works. In Sect. 3, the stability factor, fairness factor and adaptive weighting factors are introduced and then, the proposed AWCA is described in detail. Section 4 shows the computer simulation results on the life time and fairness. Finally, Sect. 5 offers some concluding remarks.

2. Cooperative Relay Network

2.1 Network Structure

The cooperative relay network considered in this paper is

Manuscript received April 17, 2011.
Manuscript revised August 9, 2011.
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DOI: 10.1587/transcom.E94.B.3251

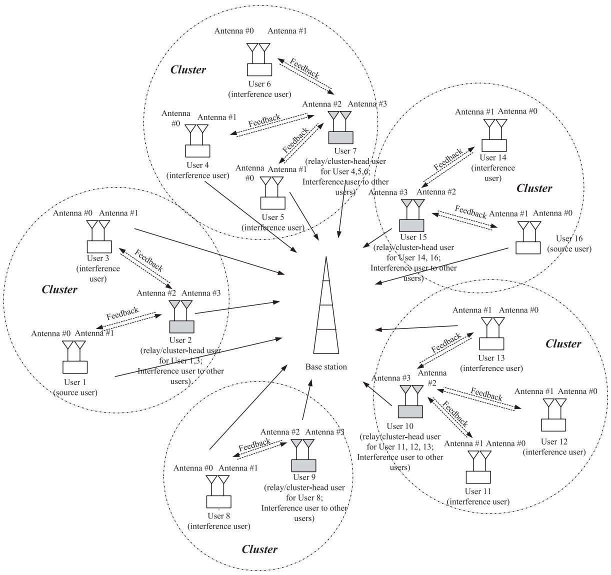


Fig. 1 Cooperative relay network. The users with gray color are the cluster-heads while the users with white color are its member nodes.

shown in Fig. 1. One of the nodes works as a cluster-head and relays the packets received from its member nodes to the base station (BS). Any node could be a cluster-head if a certain condition is satisfied. The member nodes of a cluster-head lie within the transmission range of the cluster-head. In this paper, the following assumption is used.

- The cluster-head is selected periodically.
- Each cluster-head supports only δ member nodes (where δ is the pre-defined threshold) to guarantee so that the cluster-head does not consume its battery power excessively.
- The same packet length is used for transmission.
- The cluster-head communicates with its neighbors within the transmission range.
- The transmitted packets are correctly received if communicating nodes are within the communication range.
- The energy of each node is limited since all the nodes are battery operated.
- The initial energy is the same for all nodes.
- The battery energy consumption due to signal transmission depends on the transmission range. A lower energy is required for a node to communicate with the one closer to it.

2.2 Popular Algorithms

There exist three popular algorithms: the Lowest-ID heuristic algorithm [7], Highest-degree heuristic algorithm [8] and WCA [7], [8].

1) *Lowest-ID heuristic algorithm*: this algorithm is known as an identifier-based clustering, which assigns a unique ID to each node. The node with the lowest ID is selected as a cluster-head. It has less frequent cluster-head updating and achieved higher throughput performance. However, its drawback is that the smaller IDs always lead to high battery energy consumption [7].

2) *Highest-degree heuristic algorithm*: this algorithm is viewed as a connectivity-based clustering algorithm. It computes the node degree based on its distance from others. The node with maximum number of neighbors is selected as a cluster-head. It was demonstrated that this algorithm achieves a low updating rate of cluster-heads, but provides low throughput.

3) *WCA*: this algorithm is the most popular algorithm [7], which selects the nodes with the smallest combined weight. The combined weight W_u of node u is defined as

$$W_u = w_1\Delta_u + w_2 D_u + w_3 M_u + w_4 P_u, \tag{1}$$

where Δ_u is related to the node degree defined as the number of neighbor nodes, D_u is the energy consumption, mobility M_u is the travelling speed of the node u, and P_u is the cumulative time duration during which node u acts as a cluster-head. The weighting factors, w_1, w_2, w_3, and w_4, reflect the relative importance of Δ_u, D_u, M_u, and P_u, respectively. Note that the weighting factors are often determined by experience. The weighting factors should be set according to the quality requirement, the propagation condition and the number of users.

Note that all of the above algorithms consider the fixed number of arrival users, i.e., fixed weighted factors are used for WCA. This assumption is not practical, since the number of users changes from time to time.

3. Adaptive WCA

Before describing the proposed algorithm, the stability factor S_u and the fairness factor F_u are introduced and then, the adaptive weighting factors are introduced.

3.1 Stability Factor

To consider the stability of the system, we introduce a new stability factor S_u between node u and its neighbor nodes. The HELLO message is regularly exchanged among nodes in the network to maintain the network. If the HELLO message between node u and its member nodes has been exchanged more than 3 times consecutively [14], the link is regarded as stable. We assume a four-time handshaking protocol and define the stability factor as

$$S_u = 2^{\sum_{u'=1}^{d_u}\left|10\log_{10}\left(\frac{P^{(2)}_{r,u'\to u}}{P^{(1)}_{r,u'\to u}}\right)+10\log_{10}\left(\frac{P^{(3)}_{r,u'\to u}}{P^{(2)}_{r,u'\to u}}\right)+10\log_{10}\left(\frac{P^{(4)}_{r,u'\to u}}{P^{(3)}_{r,u'\to u}}\right)\right|}. \tag{2}$$

In (2), d_u is the number of neighbor nodes within the transmission range R_{tx_range} of node u, given as

$$d_u = \text{Number}\left[\{\text{distance}\,(u, u')\} < R_{tx\_range}\right]. \tag{3}$$

$P^{(i)}_{r,u'\to u}$ is the signal power of the i-th HELLO message transmitted from node u and received by node u' and is given by

$$P^{(i)}_{r,u'\to u} = P_{u'} \cdot \left(d^{(i)}_{u'\to u}\right)^{-\alpha}, \tag{4}$$

where $d^{(i)}_{u'\to u}$ is the distance between node u' and node u, α is path loss exponent (the typical value of α is 3∼4 for urban area [21]), $P_{u'}$ is the transmit power of node u', which is given as

$$P_{u'} = \sqrt{\frac{2E_{u'}}{T_s}}, \tag{5}$$

where $E_{u'}$ is the energy of the node u', T_s is the symbol duration. $E_{u'}$ is given by

$$E_{u'} = E_0 - N_{u'\_own} \cdot E_{packet} - N_{u'\_relay} \cdot E_{packet}, \tag{6}$$

where $N_{u'\_own}$ and $N_{u'\_relay}$ are the number of original packets of node u' and the number of packets relayed by node u', respectively, E_0 is the initial battery energy, and E_{packet} is the energy required for transmission or relaying a packet to the base station.

Using the relative speed vector $V_{u'\to u}$ between node u' and node u, $d^{(i)}_{u'\to u}$ is given as

$$d^{(i)}_{u'\to u} = d_{0,u'\to u} + V_{u'\to u} \cdot T_i, \tag{7}$$

where $d_{0,u'\to u}$ is the initial distance between node u' and node u and T_i (= iT, T is the HELLO message length in time) is the time duration taken until the i-th HELLO message is exchanged. The relative speed vector $V_{u'\to u}$ is calculated as

$$V_{u'\to u} = \sum_{u'\in d_u} \frac{1}{T} \int_T \{V(u,t) - V(u',t)\}\, dt, \tag{8}$$

where $V(u,t)$ and $V(u',t)$ are the speed vectors of node u and u', respectively, at time t.

3.2 Fairness Factor

In Ref. [20], we defined two new parameters: throughput and fairness. The throughput Th_u of node u (= 0 ∼ $U-1$) is the sum of the throughput (Th_{u_own}) of a direct link between node u and BS and the throughput (Th_{u_relay}) via node u's cluster-head (relay) and is given as

$$Th_u = Th_{u\_own} + Th_{u\_relay} = \left(N_{u\_own} + N_{u\_relay}\right) \cdot I_{packet}, \tag{9}$$

where I_{packet} is number of information but per packet. The average throughput $\bar{T}h$ is defined by

$$\bar{T}h = \frac{1}{U} \sum_{u=0}^{U-1} Th_u. \tag{10}$$

The fairness is given as [20]

$$F_u = \frac{\left(\frac{1}{U}\sum_{u=0}^{U-1} Th_u\right)^2}{\frac{1}{U}\sum_{u=0}^{U-1} Th_u^2}. \tag{11}$$

If all the nodes achieve the same throughput (i.e., $Th_u = \bar{T}h$ for all u), $F = 1$ and the network is said to be fair to all the users. If $T_u \neq T'_u$, F approaches $1/U$.

3.3 Adaptive Weighting Factors

The combined weight of the proposed algorithm is defined as

$$W_u = w_s \cdot S_u + w_F \cdot (1 - F_u), \tag{12}$$

where S_u and F_u represent the stability and fairness, respectively and w_s and w_F are the weighting factors for the stability and fairness, respectively.

The users access the network independently and therefore, the number of arrival users changes from time to time. Hence, it is necessary to adaptively adjust the weighting factors, w_s and w_F, according to the number of arrival users. When the number of arrival users is small, the cost of network reconfiguration is low and therefore, the fairness is more important than the network stability. However, as the number of arrival users increases, the cost of network reconfiguration increases and hence, the network stability becomes more important. As a consequence, we use the following weighting factors, w_s and w_F

$$\begin{cases} w_s = \beta_s + \lambda \cdot \dfrac{U}{U_{\max}} \\ w_F = \beta_F + \lambda \cdot \left(1 - \dfrac{U}{U_{\max}}\right) \end{cases}, \tag{13}$$

where β_s and β_F are fixed (set by experience) and set so as to keep the network stability and fairness in an acceptable level. In the paper, we use $\beta_s = \beta_F = 0.1$ according to the preliminary computer simulation, so as to keep the performance, i.e., average life time, comparable to that of WCA. U is the number of arrival users, $U_{\max}$ is the maximum number of users, and λ is given as

$$\lambda = 1 - (\beta_s + \beta_F). \tag{14}$$

3.4 AWCA

The proposed AWCA consists of seven steps. Step 1 is used to search for the possible cooperative nodes; steps 2 to 5 compute the weighting factors and the combined weight factor to be used for selection of the cluster-head; and steps 6 and 7 select a cluster-head.

- Step 1: Find the neighbor node within its transmission range of node u. The number d_u of neighbor nodes is given as Eq. (3).
- Step 2: Compute the stability S_u according to Eq. (2).
- Step 3: Compute the fairness of the network using Eq. (11).
- Step 4: Calculate the adaptive weighting factors w_s and w_F using Eq. (13).
- Step 5: Calculate the weight W_u for node u using Eq. (12).
- Step 6: The node with the smallest W_u is selected as

the cluster-head. All the member nodes belonging to the cluster-head are no longer necessary to proceed to Step 7.

- Step 7: Repeat the steps 1-6 for the remaining nodes which have not yet been selected as a cluster-head or not yet been selected as a member of a cluster-head.

4. Simulation Results

Computer simulation was conducted to compare the performances among Lowest-ID, Highest-degree, WCA, SWCA [15], FWCA [20], and AWCA algorithms in terms of the number of cluster-heads, load balance factor (LBF), cluster-head updating rate, average life time, throughput and fairness performances. The LBF is defined as

$$\mathrm{LBF} = \frac{N_{cluster}}{\sum_{i=1}^{N_{cluster}} \left(N_{i\_memeber} - \bar{N}_{member}\right)^2}, \qquad (15)$$

where $N_{cluster}$ is the number of cluster-heads in the network, $N_{i\_memeber}$ ($1 \leq i \leq N_{cluster}$) is the number of the member nodes of the i-th cluster, $\bar{N}_{memeber} = (U - N_{cluster})/N_{cluster}$ is the average number of member nodes which are connected to the cluster-head with U being the total number of nodes in the network. Higher LBF indicates better loading balance; when the number of member nodes is the same for all cluster-heads (i.e., $N_{i\_member} = \bar{N}_{member}$), the network is regarded to have the best loading balance.

The simulation condition is shown in Table 1. For traditional clustering algorithm (i.e., Lowest-ID, Highest-degree, and WCA), the weighting factors are fixed [7] irrespective of the number of arrival users.

Assuming that the number of arrival users is U=11, we evaluated the number of cluster-heads, LBF, cluster-head updating rate, average life time of clusters, and average throughput per user, and fairness. The results are plotted in Figs. 2–7 as a function of the transmission range.

Figure 2 compares different clustering algorithms in terms of the number of cluster-heads. From Fig. 2, it can be seen that the number of cluster-head reduces with increasing transmission range. As the longer the transmission range of nodes is, the greater the cluster coverage becomes, and accordingly the cluster-head is able to serve more nodes. Among different clustering algorithms, the Highest-degree heuristic algorithm requires the smallest number of cluster-heads, since it always selects the node which has the largest number of neighbors as a cluster-head. AWCA requires more cluster-heads than Lowest-ID, WCA and Highest degree algorithms to achieve better throughput and LBF performances.

The measured LBF is plotted in Fig. 3. It can be seen from Fig. 3 that the LBF becomes large when the transmission range is either too short or too long (note that higher LBF indicates better loading balance). When the transmission range is between 20 m and 40 m, AWCA, WCA, and SWCA have similar LBF which is better than Lowest-ID,

Table 1 Simulation condition.

Parameter	Note	Value
δ	Number of member nodes/per cluster	2
U	Number of arrival users	3~30
$U_{\max}$	Maximum allowable number of users	30
Simulation run time		10000 in unit time
Location	Locations of users	Uniformly distributed in a 100m × 100m area
Speed	Moving speed	Uniformly distributed over [0-5m/s]
Direction	Direction of user movement	Uniformly distributed over [0-2π radians]
I_{packet}	Number of bits per packet	1024 kbits
Packet rate	Packet transmit rate	1packet/unit time
E_0	Initial battery energy	1500mAh
E_{packet}	energy required for transmission or relaying	0.15mAh/packet
α	Path loss exponent	3
β_s , β_F	see Eq. (13)	$\beta_s = \beta_F$ =0.1
{ w_i }	WCA: (w_1, w_2, w_3, w_4) SWCA: (w_1, w_2, w_3, w_4, w_5) FWCA: (w_1, w_2, w_3, w_4, w_5)	(0.2, 0.05, 0.7, 0.05) (0.05, 0.05,0.0 5, 0.05, 0.8) (0.05, 0.05,0.0 5, 0.05, 0.8)
R_{tx_range}	Transmission range	5~100m

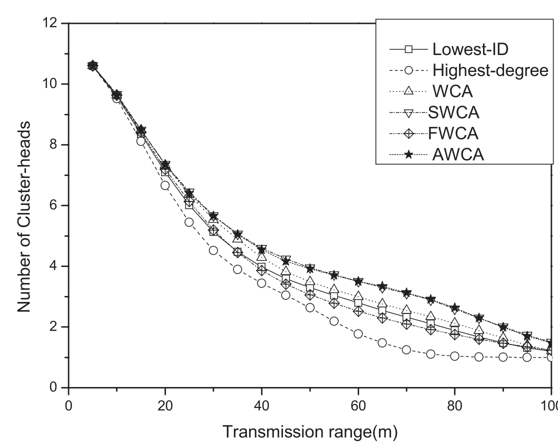


Fig. 2 Number of cluster-heads.

Highest-degree, and FWCA algorithms. When the transmission range is longer than 40 m, the LBF of the Highest-degree heuristic algorithm is higher than other algorithms since it has the smallest number of cluster-heads in the network. The LBF of AWCA is comparable to WCA. The transmission range of a node cannot be too long because of the transmit power limitation. For a transmission range of shorter than 40 m, AWCA always provides a better LBF performance than other algorithms.

The cluster-head updating rate (times/unit time) is a very important measurement to compare different clustering algorithms [6]. In Fig. 4, the cluster-head updating rate

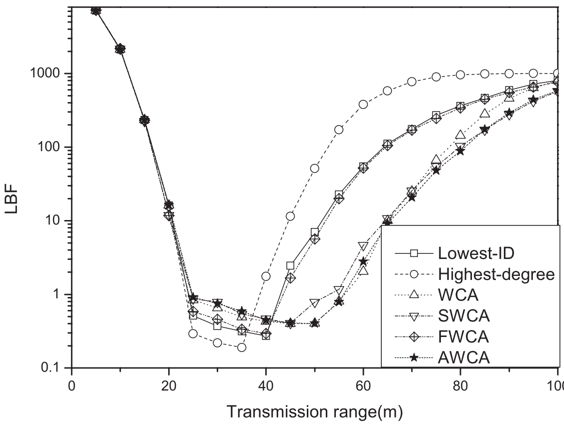


Fig. 3 LBF.

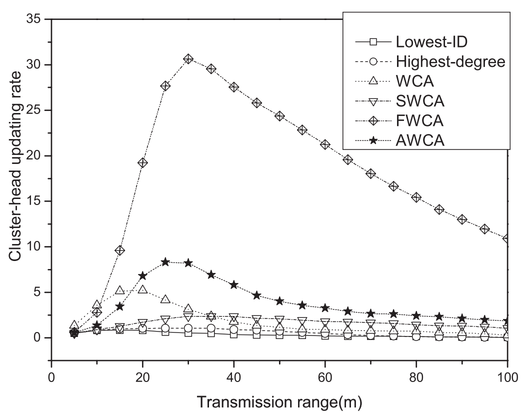


Fig. 4 Cluster-head updating rate.

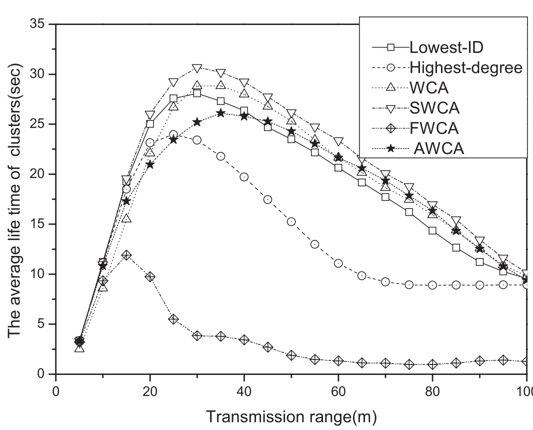
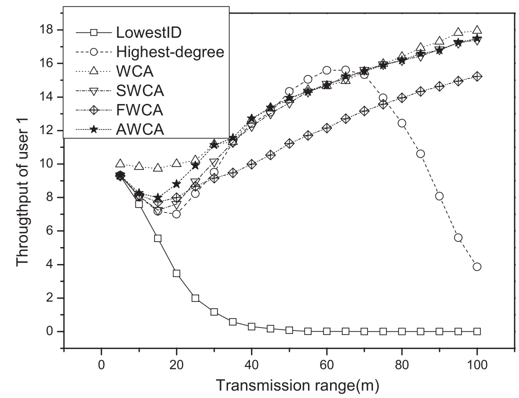
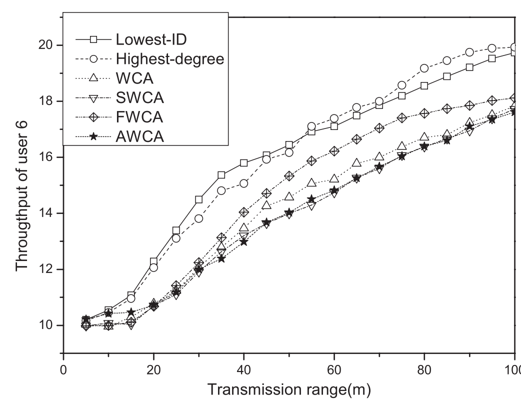


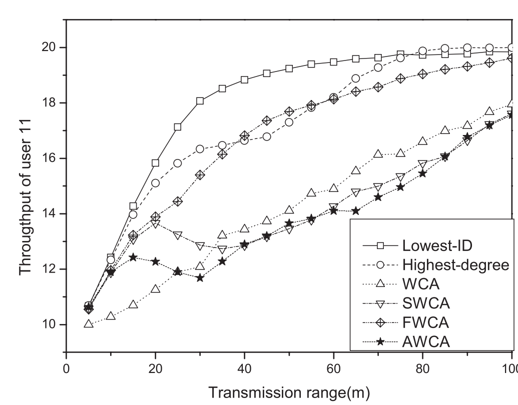
Fig. 5 Impact of transmission range on the average life time of clusters.



a) Node *u*=1.



b) Node *u*=6.



c) Node *u*=11.

Fig. 6 Average throughput per node.

is plotted as a function of the transmission range. The average received signal power P_r is expressed as $P_r \propto P_t \times d^{-\alpha}$ [21], where P_t, d, and α are the transmit power, distance, and path loss exponent, respectively. Therefore, the transmission range is given by $d \propto (P_t/P_r)^{1/\alpha}$ for the given transmit and receive powers, P_t and P_r. It is seen from Fig. 4 that with increasing transmission range, the cluster-head updating rate increases at beginning and reaches the maximum when the transmission range approaches around 25 m; however, as the transmission range increases beyond 25 m, cluster-head updating rate starts to decrease.

When the transmission range is 30 m, cluster-head updating rate is 0.54, 1.1, 3.1, 2.4, 31, and 8.2 times per/unit time for Lowest-ID, Highest-degree, WCA, SWCA, FWCA, and AWCA, respectively. FWCA has the highest updating rate while Lowest-ID has the lowest updating rate. SWCA takes into account the stability in the weight computation while FWCA does not. Therefore, SWCA has lower up-

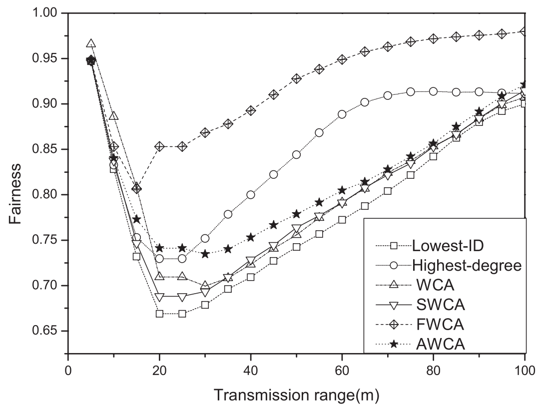


Fig. 7 Fairness.

dating rate than WCA and FWCA. AWCA has the updating rate between SWCA and FWCA.

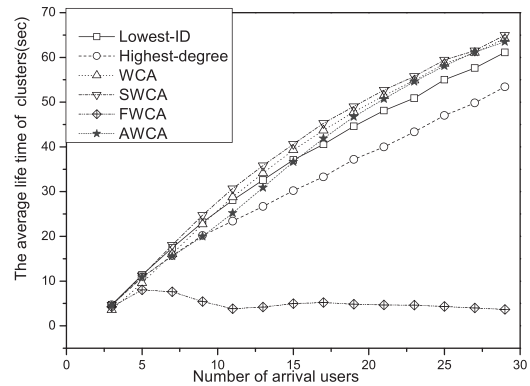
The average life time of clusters is plotted in Fig. 5. If the transmission range is 40 m, the average life time is about 26s for AWCA while it is 26, 10, 28, 29, and 3.4 s for Lowest-ID, Highest-degree, WCA, SWCA and FWCA respectively. Although SWCA has the longest life time than other algorithms, AWCA has the life time similar to SWCA.

The throughputs of nodes u=1, 6, and 11 among U=11 users are plotted in Fig. 6. The throughput was measured as the correctly received packets normalized by the life time of that user. The packets are assumed to be received correctly if the nodes are within their communication range.

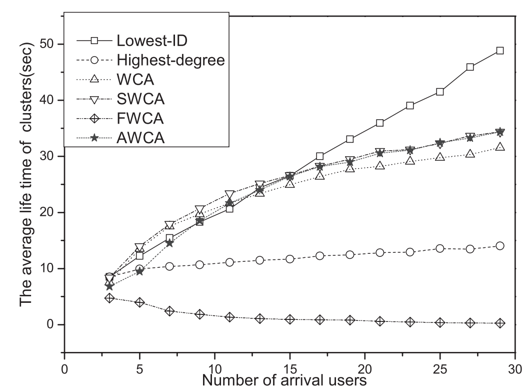
Consider the throughput of node u=1 (which is used as a cluster-head for the Lowest-ID algorithm all the time). Lowest-ID provides the worst throughput for node u=1. When comparing to other algorithms, the throughput of node u=1 is comparable to other nodes, since node u=1 does not act as a cluster-head. Although the throughputs of node u=6 and node u=11 are different for a different algorithm, both AWCA and FWCA provide higher throughput than other algorithms.

Each node may have a different throughput (i.e., $T_u \neq T'_u$ if $u \neq u'$). If all nodes have the same throughput (i.e., $T_u = T$ for all u), the network is said to be fair. The fairness performance when the transmission range is 20 m is plotted in Fig. 7. FWCA provides the best fairness. Although AWCA has a lower fairness than FWCA, it achieves the fairness close to SWCA. Note that the fairness and networks stability are in a tradeoff relationship. To improve the fairness, frequent cluster-head updating is necessary. This leads to lower network stability.

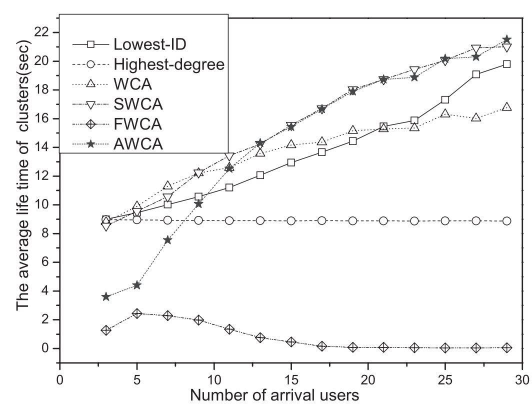
Figures 8 shows the impact of the number of arrival users on the average life time for a fixed transmission range R_{tx_range} (i.e., R_{tx_range} = 30, 60, and 90m). It is seen from Fig. 8 that although SWCA provides overall the longest life time (except for a case of R_{tx_range}=60m), the proposed AWCA provides the life time longer than FWCA and close to SWCA. In particular, when the number of arrival users is large, AWCA has the life time longer than FWCA and similar to SWCA



a) $R_{tx\_range} = 30m$.



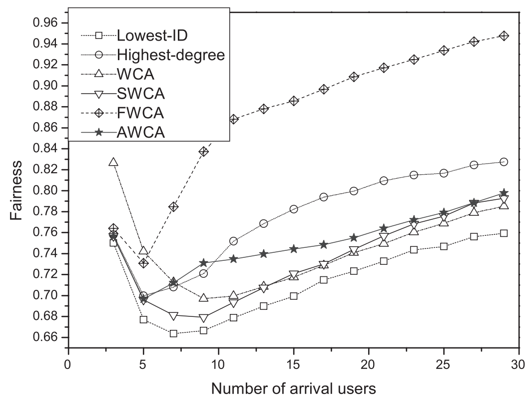
b) $R_{tx\_range} = 60m$.



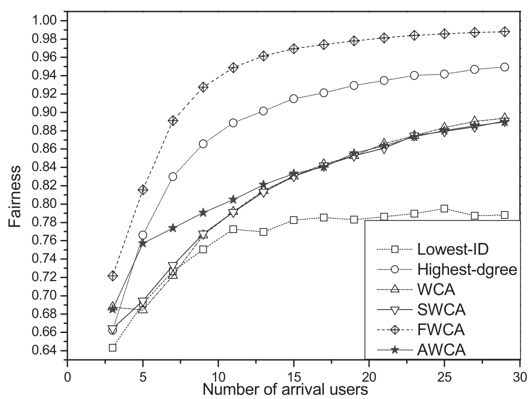
c) $R_{tx\_range} = 90m$.

Fig. 8 Impact of the number of arrival users on the average life time of clusters.

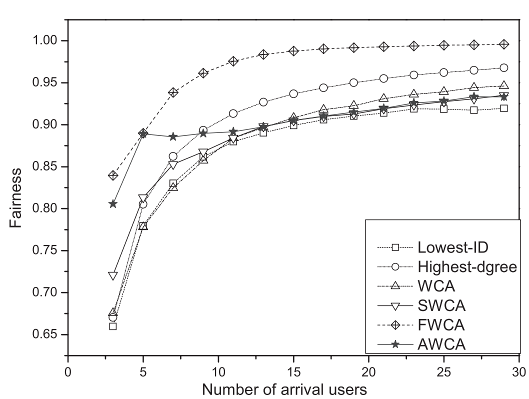
Figure 9 shows the impact of the number of arrival users on the fairness for a fixed transmission range R_{tx_range} (i.e., R_{tx_range}=30, 60, and 90 m). It is seen from Fig. 9 that although FWCA provides the highest fairness followed by Highest-degree, AWCA provides higher fairness than SWCA. In particular, when the number of arrival users is small, AWCA provides fairness close to FWCA.



a) $R_{tx\_range} = 30m$



b) $R_{tx\_range} = 60m$



c) $R_{tx\_range} = 90m$

Fig. 9 Impact of the number of arrival users on the fairness.

5. Conclusion

This paper proposed an adaptive weighted clustering algorithm (AWCA), which introduces the weighting factors to control both the stability and fairness according to the number of arrival users. We investigated, by the computer simulation, the performances achievable with AWCA in terms of the number of cluster-heads, LBF, cluster-head updating rate, average life time, throughput and fairness. It was shown by the computer simulation that when the number of arrival users is large, AWCA has the life time longer than FWCA and similar to SWCA and that when the number of arrival users is small, AWCA provides fairness higher than SWCA and close to FWCA.

Acknowledgments

This study was supported by China National Science Foundation under Grand No.60872016, the Fundamental Research Funds for the Central Universities (Grant No.HIT.NSRIF.201148), Program for New Century Excellent Talents (NCET-08-0157) in University, and partly supported by Tohoku University GCOE program.

References

[1] M. Meinesz, F. Schoute, and J.D. Bakker, "A fixed network design for site diversity enhanced wireless access," Proc. IEEE Veh. Technol. Conference (VTC1999-Fall), vol.2, pp.1033–103, Sept. 1999.

[2] J.D. Bakker and R. Prasad, "A multiple access protocol implementation for a virtual cellular network," Proc. IEEE Veh. Technol. Conference (VTC-Spring), pp.1707–1711, May 1999.

[3] Y. Jing, X. Mai, and X. Jinfu, "A cluster-based multipath delivery scheme for wireless sensor networks," Proc. IEEE International Conference on Broadband Network & Multimedia Technology (IC-BNMT), pp.18–20, Oct. 2009.

[4] S. Nesargi and R. Prakash, "Distributed wireless channel allocation in networks with mobile base stations," IEEE Trans. Veh. Technol., vol.51, no.6, pp.1407–1421, Nov. 2002.

[5] H.J. Kim and J.P. Linnartz, "Virtual cellular network: A new wireless communications architecture with multiple access ports," Proc. IEEE Veh. Technol. Conference (VTC1994-Spring), pp.1055–1059, June 1994.

[6] J. Li, M. Li, and X. Yang, "Cluster based multi-populations genetic algorithm in noisy environment," Proc. 2009 Chinese Conference on Pattern Recognition. (CCPR 2009) and the First CJK Joint Workshop on Pattern Recognition (CJKPR), pp.2–3, Nov. 2009.

[7] M. Chatterjee, S.K. Das, and D. Turgut, "WCA: A weighted clustering algorithm for mobile ad hoc networks," IEEE Clustering Computing, vol.5, no.2, pp.193–204, May 2002.

[8] M. Chatterjee, S.K. Das, and D. Turgut, "An on-demand weighted clustering algorithm (WCA) for ad hoc networks," Proc. IEEE GLOBECOM 2000, pp.1697–1701, Nov. 2000.

[9] C.R. Lin and M. Gerla, "A distributed control scheme in multi-hop packet radio networks for voice/data traffic support," Proc. IEEE GLOBECOM, pp.1238–1242, June 1995.

[10] S.K. Dhurandher and G.V. Singh, "Weight based adaptive clustering in wireless ad hoc networks," Proc. IEEE International Conference on Personal Wireless Communications, pp.23–25, Jan. 2005.

[11] P. Basu, N. Khan, and T.D.C. Little, "A mobility based metric for clustering in mobile ad hoc networks," Proc. 21st International Conference on Distributed Computing Systems Workshops, pp.413–418, April 2001.

[12] L. Subramanian and R.H. Kartz, "An architecture for building self-configurable systems," Proc. IEEE/ACM Workshop on Mobile Ad Hoc Networking and Computing, Boston, Aug. 2000.

[13] R. Dube, C. Rais, K. Wang, and S. Tripathi, "Signal stability based adaptive routing (SSA) for ad-hoc mobile networks," IEEE Pers. Commun., vol.4, no.1, pp.36–45, Feb. 1997.

[14] M. Gerharz, C. Waal, M. Frank, and P. Martini, "Link stability in mobile wireless adhoc networks," Proc. 27th Annual IEEE Conference on Local Computer Networks, pp.30–39, Nov. 2006.

[15] Q. Yu, N. Zhang, W. Meng, and F. Adachi, "A novel stability weighted clustering algorithm for multi-hop packet radio virtual cellular network," IEEE WCNC2010, Sydney, Australia, April 2010.
[16] L. Dai and L.J. Cimini, Jr., "Improved fairness in energy-constrained cooperative ad-hoc networks," Proc. IEEE Conference on Information Sciences and Systems (CISS), pp.734–738, March 2006.
[17] L. Dai, W. Chen, K.B. Letaief, and Z. Cao, "A fair multiuser cooperation protocol for increasing the throughput in energy-constrained ad-hoc networks," Proc. IEEE ICC'06, pp.3633–3638, Istanbul, Turkey, June 2006.
[18] R. Khalaf and I. Rubin, "Improving the bit-per-joule performance of IEEE 802.11 based wireless networks through high power transmissions," Proc. International Conference on Computer Communications and Networks (ICCCN), pp.1–6, Aug. 2008.
[19] L. Feeney and M. Nilsson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment," Proc. IEEE Infocom, pp.1548–1557, April 2001.
[20] Q. Yu, N. Zhang, W.X. Meng, and F. Adachi, "A novel fairness weighted clustering algorithm for multi-hop packet radio virtual cellular network," IEEE VTS APWCS2010, Taiwan, May 2010.
[21] M. Hata, "Empirical formula for propagation loss in and mobile radio services," IEEE Trans. Veh. Technol., vol.VT-29, no.3, pp.317–325, 1980.

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