Broadcasting with Optimized Transmission Efficiency in Wireless Networks

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***Abstract* — One of the fundamental operations in the wireless network is broadcasting, which is widely used to disseminate information throughout the network. Flooding is a simple method to realize broadcasting. However, flooding will incur a large number of redundant retransmissions, leading to low transmission efficiency. In this paper, we propose an optimized broadcast protocol (OBP) to improve the transmission efficiency. In OBP, each node calculates the retransmission locations based on a hexagon ring pattern in order to minimize the number of retransmissions. Only the nodes nearest to the calculated locations need to retransmit the packet. As shown by analysis, the transmission efficiency bound of OBP is 0.55, which approximates the theoretical optimal bound 0.61 by a ratio of 90%. We also compare OBP with a related protocol called OFP in terms of transmission efficiency and reachability.**

Keywords: broadcasting; flooding; covering problem; hexagon lattice; transmission efficiency; wireless network

I. INTRODUCTION

Broadcasting is one of the fundamental operations to disseminate information throughout a wireless network. The operation has many applications; for example, many routing protocols rely on broadcasting packets to find routing paths. Flooding is an intuitive approach in the implementation of broadcasting, in which each node retransmits a packet when receiving it at the first time. Flooding is simple and is highly reliable; however, it may cause the broadcast storm problem [9] and has low *transmission efficiency* due to redundancy of retransmissions. As shown in [7], the theoretical upper bound of transmission efficiency is 0.61. To take two communicating nodes A and B in Fig. 1 as an example, the transmission efficiency is the ratio of the effective communication area (the area covered by circles C_A or C_B, i.e., $|C_A \cup C_B|$) over the total communication area (the summation of areas of C_A and C_B, i.e., $|C_A|+|C_B|$), where C_A and C_B are the circles centered respectively at A and B with the radius of R, the transmission range. When the distance between nodes A and B equals to the transmission range R, the transmission efficiency reaches the theoretical upper bound 0.61.

Some broadcast protocols for wireless networks have been proposed in the literature [2-3, 7, 9, 11-13]. Among them, *geometry-based protocols*, which assume that each node is aware of its own location to make retransmission decisions, have good transmission efficiency. For example, the *Optimal Flooding Protocol (OFP)*[1] [11] has transmission efficiency of 0.41, which is about 67% of the theoretical upper bound. The idea of OFP is based on a regular hexagonal partition of the network with the side length of R, where only the nodes nearest to hexagon vertexes need to retransmit the broadcast packet sent by the source node S (please refer to Fig. 2).

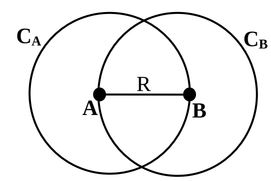

Figure 1. Illustration of optimal transmission efficiency

In this paper, we propose a more efficient geometry-based broadcast protocol, called *Optimized Broadcast Protocol (OBP)*, to optimize the transmission efficiency by keeping as few as possible retransmissions. In OBP, a node counts on hexagon rings centered at the source node S to decide if it should rebroadcast a packet when receiving the packet at the first time. Fig. 3 shows the hexagon rings centered at the source node S, where only nodes nearest to hexagon centers (represented as ●) and specific hexagon vertexes (represented as ▲) need to rebroadcast the packet. As we will show, OBP's transmission efficiency can reach 0.55, which is about 90% of the theoretical upper bound.

The rest of this paper is organized as follows. In Section II, we introduce some related work. In Section III, we propose OBP. The transmission efficiency analysis is given in Section IV and performance comparison is described in Section V. At last, some concluding remarks are drawn in Section VI.

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[1] A similar protocol called *Hexagon Flooding* is proposed in [7]. Yet another similar protocol called *optimized Broadcast Protocol for Sensor networks (BPS)* is proposed in [3].

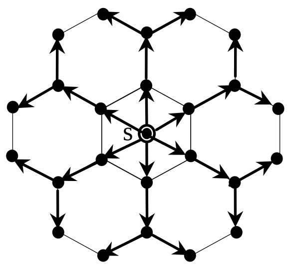

Figure 2. Broadcasting via hexagon vertexes in OFP

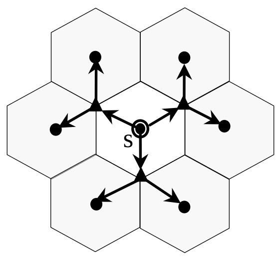

Figure 3. Broadcasting via hexagon centers and vertexes in OBP

II. Related Work

Flooding is an intuitive method to broadcast a packet throughout the entire network. In the flooding protocol, each node retransmits a packet when receiving it at the first time. The flooding protocol is simple, but may lead to a large number of redundant forwarding packets, which consumes much energy and raises the possibility of packet collision. Many broadcast protocols [2-3, 7, 9, 11-13] are proposed to improve the flooding protocol. They can be generally classified as the *Connected Dominating Set (CDS)* approaches and the *geometry* approaches.

The CDS approaches select a number of nodes for retransmitting a packet to reach all nodes on the basis of unit disk graph, where two nodes have an edge between them if they are within each other's transmission range. Given a graph G(V,E), where V is a node set and E is an edge set, a CDS is a subset $V' \subseteq V$ such that each node in $V-V'$ (i.e., in V but not in the V') connects to at least one node in V', while V' is connected. To find a CDS for any given graph is proved to be an NP-hard problem in [4]. Even in a unit disk graph, to find a *minimum CDS* (or *MCDS*), the CDS with the minimum number of nodes, is also NP-hard [8]. Assuming each node knows the global topology of the network, Das and Bhargavan in [2] proposed two global algorithms to find the MCDS based on Guha's approximation algorithm in [5]. The two global algorithms work under the restriction that each node knows the entire topology of the network. To eliminate the restriction, Wu and Li in [13] proposed a localized distributed algorithm to find a CDS and then prune redundant nodes to approximate the MCDS. However, as reported in [1], the approximation ratio of the algorithm may not be so good in large networks.

The geometry approaches assume that each node is aware of its own location to make retransmission decisions. They usually have good transmission efficiency. For example, the Optimal Flooding Protocol (OFP) [11] has transmission efficiency of 0.41, i.e. 67% of the theoretical bound. To the best of our knowledge, OFP has the highest transmission efficiency among all existed geometry-based protocols. OFP is based on a regular hexagonal partition of the network and only the nodes nearest to hexagon vertexes need to rebroadcast the packet. As shown in Fig. 4, a source node in OFP first broadcasts a packet. And the node nearest to the vertex location (1) is responsible for rebroadcasting. Then, the node nearest to the location (11) is responsible for rebroadcasting. And then, the nodes nearest to the locations (111) and (112) are responsible for rebroadcasting, and so on. Similarly, the other nodes nearest to the vertex locations (2), (3),…, (6), (21), (211), (212), … are responsible for rebroadcasting. In this way, the broadcast packet can be delivered to all nodes in the network.

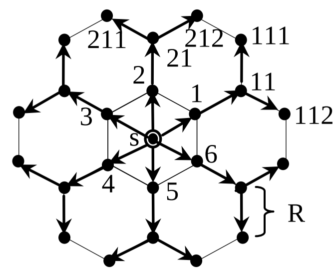

Figure 4. The illustration of transmissions in OFP

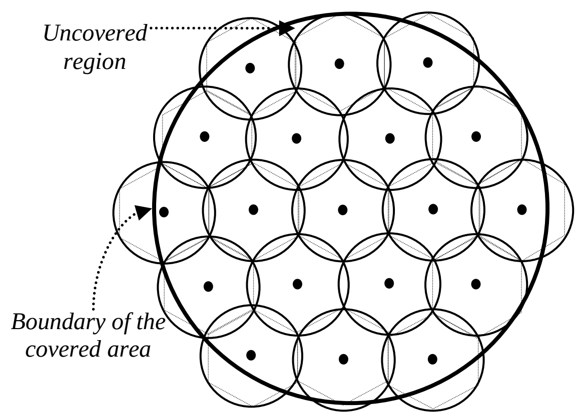

Figure 5. The illurstation of the covering problem

The design idea of OFP is related to the *covering problem* [6], which asks "How to arrange circles such that the minimum number of circles can completely cover a given area?" To quantify the efficiency of the solutions to this problem, Kershner in [6] defined the *covering efficiency* $\rho=A_T/A_E$, where A_T is the total summation of circles' areas and A_E is the effective covered area. Smaller ρ is preferred. If a solution uses fewer circles to cover the area, the summation of circles' areas (A_T) will become smaller, and ρ will thus become smaller. It is worth mentioning that if we assume that the center of each circle has a transmitting node with the circle being the transmission range, then the circles' covering efficiency is the reciprocal of the nodes' transmission efficiency.

As shown in [6], the lower bound of ρ is $2\sqrt{3}\pi/9$ (≈1.209), which is achieved by placing circles according to a *regular hexagonal lattice*, as shown in Fig. 5. It is remarkable that some uncovered regions exist near the boundary of the covered area. This is called the *boundary effect*. However, the uncovered regions approximate zero and the boundary effect can be ignored if the circle is small enough when compared with the covered area.

III. The Optimized Broadcast Protocol (OBP)

A. Details of the Protocol

The basic concept of OBP is simple and is described as follows. The entire area is partitioned into hexagon rings centered at the broadcast source node S, where hexagons are of the side length of R, the transmission range (see Fig. 6). If every node nearest to a hexagon center (below, we use *center node* to stand for such a node for short) is activated to forward the broadcast packet, then the entire network area is fully covered and all nodes can receive the broadcast packet.

The hexagon rings have only one hexagon in the central (level-0) ring, and have six hexagons in the level-1 ring, and so on. In general, there are 6*k* hexagons in the level-*k* ring. A hexagon center in the level-*k* ring is denoted as $C_{k,i}$, where *i* is an index ranging from 0 to 6*k*-1. Centers indexed by 0 lie on the horizontal axis staring from S towards right, while other centers are indexed counterclockwise. The *relative location* $LC_{k,i}$ of $C_{k,i}$ relative to S can be derived handily by a *geometric mapping* $M(C_{k,i})\rightarrow LC_{k,i}$. The geometric mapping will be well defined in subsection III-B.

In OBP, the source node S (associated with $C_{0,0}$) should send the broadcast packet and activate six center nodes (associated with $C_{1,0},\ldots,C_{1,5}$) in the level-1 ring to forward the packet. And each center node associated with $C_{k,i}$ in the level-*k* ring, $k\geq1$, should either activate no node or activate two neighboring center nodes in the next level. Actually, for $k\geq1$, $3(k+1)$ center nodes in the level-*k* ring need to activate 2 neighboring center nodes in the level-(k+1) ring, while $3(k-1)$ nodes need not to activate any node. For example, all 6 level-1 center nodes need to activate 2 level-2 center nodes, and thus all 12 level-2 center nodes can be activated properly. For another example, 9 (resp., 3) out of 12 level-2 center nodes need to (resp., need not to) activate 2 level-3 center nodes, and thus all 18 level-3 center nodes can be activated properly. We devise a mapping called the *activation target mapping* $T(C_{k,i})$ that outputs an empty set or a set $\{C_{k+1,w}, C_{k+1,w+1}\}$ of two next-level neighboring center nodes for $C_{k,i}$, $k\geq1$, to activate. Note that $C_{k+1,w}$ (resp., $C_{k+1,w+1}$) must be a neighboring center node of $C_{k,i}$; i.e., the associated hexagons of $C_{k,i}$ and $C_{k+1,w}$ (resp., $C_{k+1,w+1}$) must share an edge. The activation target mapping will be well defined in subsection III-C.

By the node activation process just mentioned, all center nodes can be activated to transmit the packet to cover the entire network area. However, since two center nodes cannot communicate with each other directly, we need intermediate nodes between them for relaying the packet. OBP chooses *vertex nodes* (i.e., the node nearest to a hexagon vertex) as the intermediate nodes to take the advantage that a vertex node can reach two center nodes (e.g., $V_{1,0}$ can reach $C_{1,0}$ and $C_{1,1}$). In OBP, S takes 3 vertex nodes associated with $V_{1,0}$, $V_{1,1}$, and $V_{1,2}$ as intermediate nodes, while the other center node associated with $C_{k,i}$ takes only 1 (or 0) vertex node associated with $V_{k+1,i}$. The relative location $LV_{k,i}$ of $V_{k,i}$, $k>1$, relative to S can be derived by computing the location of the center of $C_{k-1,i}$, $C_{k,w}$, and $C_{k,w+1}$ if $C_{k-1,i}$ should activate $C_{k,w}$ and $C_{k,w+1}$ (i.e., $T(C_{k-1,i})=\{C_{k,w}, C_{k,w+1}\}$). Note that for k=1, $LV_{1,i}$ is the location of the center of S, $C_{1,2i}$, and $C_{1,2i+1}$ for i=0,1,2.

The broadcast packet of OBP is of the format P(LS, F), where LS is the absolute location of the source node, and F is the set of relative locations of intended forwarding nodes in the next-level ring. Note that each packet is sent along with a unique packet ID so that a node can decide if the packet has ever been received. Also note that the relative locations are sent along with the indexes of center nodes or vertex nodes. That is, when a location $LC_{k,i}$ or $LV_{k,i}$ is sent, the indexes *k* and *i* are also sent in the packet. Those indexes are very important for a node to calculate the relative locations of intended forwarding nodes by the activation target mapping and the geometric mapping.

Below, we present the proposed protocol OBP.

Optimized Broadcast Protocol (OBP)

The step for the source node S to broadcast a packet P:

1. S sends the packet P(LS, F) with $F=\{LV_{1,0}, LV_{1,1}, LV_{1,2}\}$.

Steps for other node X receiving P(LS, F):

1. If X receives P at the first time, it registers P. Otherwise, it drops P and stops.

2. If X is not a node nearest to a location in F, it stops.

3. If X is nearest to a center node associated with $C_{k,i}$ of a location in F and $T(C_{k,i})\neq\phi$, then X sends P(LS, F′) and stops, where $F'=\{LV_{k,i}\}$.

4. If X is nearest to a vertex node associated with $V_{k,i}$ of a location in F, then X derives $\{C_{k,w}, C_{k,w+1}\}$ by calling $T(C_{k-1,i})$, sets $F'=\{LC_{k,w}, LC_{k,w+1}\}$, sends P(LS, F′) and stops.

Note that the paper [10] proposes two mechanisms to determine whether a node X is the one nearest to a given location. The first mechanism is to make nodes periodically exchange location information with neighboring nodes so that each node can properly elect the node nearest to the given location. The second mechanism is to enforce a backoff timer which is inversely proportional to the distance between a node's location and the given location. The node nearest to the given location thus has the shortest backoff timer and will earliest issue a response, which in turn prohibits other nodes from responding.

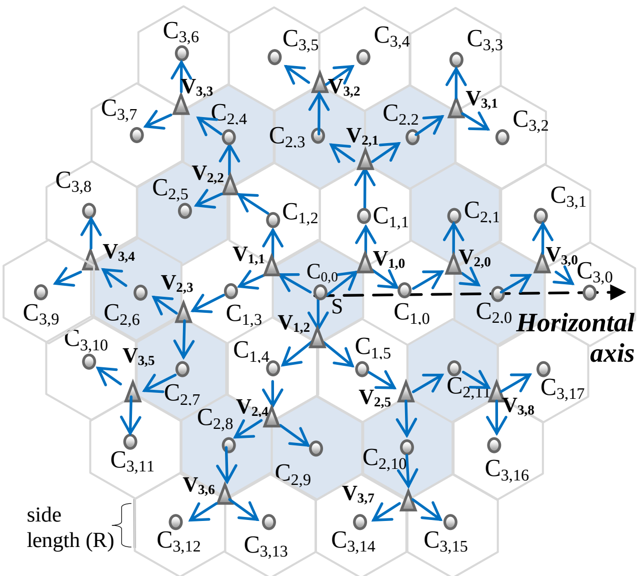

Figure 6. Transmissions of OBP in hexagon rings

B. Geometric Mapping

In this subsection we present the geometric mapping $M(C_{k,i})$ that maps a hexagon center node $C_{k,i}$ to a location $L_{k,i}$ relative to the source node S. As shown in Fig. 7, each hexagon ring can be partitioned into six sectors, indexed by 0,..,5, with each sector having k hexagon centers in the level-k ring. Let $Z_{k,q}$ denote the location relative to S of the first hexagon center in the sector q of the level-k hexagon ring (e.g., $Z_{2,0}$ is the location of the hexagon center on the horizontal line from S towards right). We have $Z_{k,q} = (k\sqrt{3}R \cdot \cos(q \cdot 60°), k\sqrt{3}R \cdot \sin(q \cdot 60°))$ for q=0,..,5, where R is the transmission range or the hexagon side length. Since each sector has k hexagon centers, we can figure out that hexagon center $C_{k,i}$ is within sector q, where $q = \lfloor i/k \rfloor$. Now we can define the geometric mapping $M(C_{k,i})$ as follows. (Note that "+" represents the vector addition operator in the mapping and the following location calculations.)

Let $q = \lfloor i/k \rfloor$. If i is a mutiple of k, $M(C_{k,i}) = Z_{k,q}$.

Otherwise, $M(C_{k,i}) =$

$$\begin{cases} Z_{k,0} + \left(-i\frac{\sqrt{3}R}{2}, i\frac{3R}{2}\right), \text{if } q = 0 \\ Z_{k,1} + ((k-i)\sqrt{3}R, 0), \text{if } q = 1 \\ Z_{k,2} + \left((q \cdot k - i)\frac{\sqrt{3}R}{2}, (q \cdot k - i)\frac{3R}{2}\right), \text{if } q = 2 \\ Z_{k,3} + \left((i - q \cdot k)\frac{\sqrt{3}R}{2}, (q \cdot k - i)\frac{3R}{2}\right), \text{if } q = 3 \\ Z_{k,4} + ((i - q \cdot k)\sqrt{3}R, 0), \text{if } q = 4 \\ Z_{k,5} + \left((i - q \cdot k)\frac{\sqrt{3}R}{2}, (i - q \cdot k)\frac{3R}{2}\right), \text{if } q = 5 \end{cases} \quad (1)$$

In Fig. 7, we illustrate the above mapping by two examples. The first example is about $M(C_{2,1})$. Since q=⌊1/2⌋=0, we calculate $Z_{2,0} = \left(2\sqrt{3}R \cdot \cos(0), 2\sqrt{3}R \cdot \sin(0)\right) = (2\sqrt{3}R, 0)$. We then have $M(C_{2,1}) = Z_{2,0} + \left(-\frac{\sqrt{3}R}{2}, \frac{3R}{2}\right)$. The second example is about $M(C_{2,7})$. Since $q = \lfloor 7/2 \rfloor = 3$, we calculate $Z_{2,3} = \left(2\sqrt{3}R \cdot \cos(180°), 2\sqrt{3}R \cdot \sin(180°)\right) = (-2\sqrt{3}R, 0)$. We then have $M(C_{2,7}) = Z_{2,3} + \left(\frac{\sqrt{3}R}{2}, -\frac{3R}{2}\right)$.

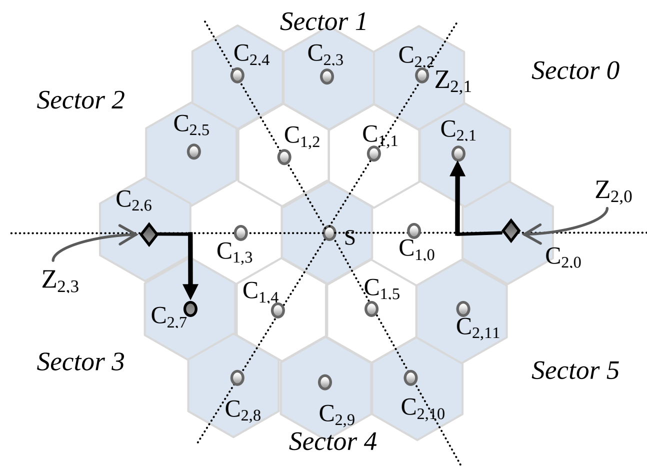

Figure 7. The illurstartion of geometric mapping

C. Activation Target Mapping

In this subsection we present the activation target mapping $T(C_{k,i})$. The input of $T(C_{k,i})$ is a center node $C_{k,i}$ for k≥1. $T(C_{k,i})$ is to find two next-level neighboring center nodes $C_{k+1,w}$ and $C_{k+1,w+1}$ of $C_{k,i}$, where w is even. If such neighboring nodes exit, the output of $T(C_{k,i})$ is $\{C_{k+1,w}, C_{k+1,w+1}\}$; otherwise, the output is an empty set. For example, $T(C_{1,0})=\{C_{2,0}, C_{2,1}\}$ since $C_{k+1,w}$ is $C_{2,0}$ and $C_{k+1,w+1}$ is $C_{2,1}$ with w=0. For another example, $T(C_{2,1})=\phi$, since the index w of the neighboring center nodes $C_{3,1}$ and $C_{3,2}$ of $C_{2,1}$ is odd.

As shown in Fig. 8, each hexagon ring can be partitioned into six sectors, indexed by 0,..,5, each having a starting axis (i.e., A0, ,…, A5). Let $q=\lfloor i/k \rfloor$ denote the index of the sector in which $C_{k,i}$ resides. $T(C_{k,i})$ is defined as follows.

$T(C_{k,i}) =$

$$\begin{cases} \{C_{k+1,i}, C_{k+1,i+1}\}, \text{ if } q = 0 \text{ and } i \text{ is even} \\ \{C_{k+1,i+1}, C_{k+1,i+2}\}, \text{ if } q = 1 \text{ and } i \text{ is odd} \\ \{C_{k+1,i}, C_{k+1,i+1}\}, \text{ if } q = 1, (i \bmod k) = 0 \text{ and } i \text{ is even} \\ \{C_{k+1,i+2}, C_{k+1,i+3}\}, \text{ if } q = 2 \text{ and } i \text{ is even} \\ \{C_{k+1,i+3}, C_{k+1,i+4}\}, \text{ if } q = 3 \text{ and } i \text{ is odd} \\ \{C_{k+1,i+2}, C_{k+1,i+3}\}, \text{ if } q = 3, (i \bmod k) = 0 \text{ and } i \text{ is even} \\ \{C_{k+1,i+4}, C_{k+1,i+5}\}, \text{ if } q = 4 \text{ and } i \text{ is even} \\ \{C_{k+1,i+5}, C_{k+1,i+6}\}, \text{ if } q = 5 \text{ and } i \text{ is odd} \\ \{C_{k+1,i+4}, C_{k+1,i+5}\}, \text{ if } q = 5, (i \bmod k) = 0 \text{ and } i \text{ is even} \\ \emptyset, \text{ otherwise} \end{cases} \quad (2)$$

The definition of $T(C_{k,i})$ contains 10 cases of different conditions. The first case (q=0 and i is even) drives the center node $C_{k,i}$ to activate two neighboring center nodes $C_{k+1,i}$ and $C_{k+1,i+1}$ in the next level, only if $C_{k,i}$ is in sector 0 and i is even. The second case (q=1 and i is odd) drives $C_{k,i}$ to activate $C_{k+1,i+1}$ and $C_{k+1,i+2}$, only if $C_{k,i}$ is in sector 1 and i is odd. The third case (q=1, (i mod k)=0 and i is even) drives $C_{k,i}$ to activate $C_{k+1,i}$ and $C_{k+1,i+1}$, only if $C_{k,i}$ is in sector 1, $C_{k,i}$ is on the starting axis of sector 1 (i.e. A1), and i is even. Similarly, the fourth, ..., and the ninth cases drive $C_{k,i}$ in the sectors 2, …, and 5 to activate two center nodes for specific conditions. The last case drives $C_{k,i}$ not to active any node, only if none of the first nine conditions is satisfied.

In Fig. 8, we illustrate $T(C_{k,i})$ by three examples. The first example is about $T(C_{2,0})$. Let $q=\lfloor 0/2 \rfloor=0$. Since q is 0 and i (=0) is even, we have $T(C_{2,0})=\{C_{3,0},C_{3,1}\}$. The second example is about $T(C_{2,5})$. Let $q=\lfloor 5/2 \rfloor=2$. Since q is 2 and i (=5) is not even, we have $T(C_{2,5})=\phi$, which means the node $C_{2,5}$ needs not to activate any node. The third example is about $T(C_{2,2})$. Let $q=\lfloor 2/2 \rfloor=1$. Since q is 1, i (=2) is even, and i is a multiple of k (=2), we have $T(C_{2,2})=\{C_{3,2},C_{3,3}\}$.

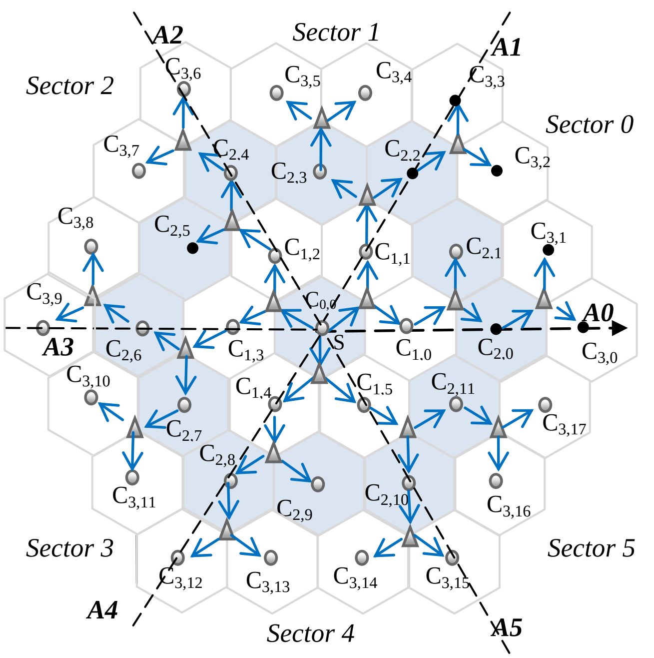

Figure 8. The illurstartion of the activation target mapping with six sectors (sector 0, …, sector 5), each having one starting axis (i.e. A0, … A5) to indicate the starting center nodes in the sector

IV. Performance Analysis

In this section, we analyze the upper bound of transmission efficiency of the proposed protocol OBP. As defined in [11], the transmission efficiency η is the ratio of the effective area to the total summation of nodes' broadcasting areas. That is,

$$\eta = \frac{T_A}{N_T A_R} = \frac{T_A}{N_T \pi R^2} \tag{3}$$

In Eq. (2), T_A is the total effective area, N_T is the number of transmitting nodes involved in broadcasting, and A_R is the transmission area of the value πR^2. In OBP, N_T equals to the number N_C of center nodes plus the number N_V of selected vertex nodes; i.e. $N_T=N_C+N_V$. The broadcasting in OBP is performed from the source node S to the center or vertex nodes of outer hexagon rings level by level. As shown earlier, there are $6k$ hexagons in the level-k hexagon ring. If the entire network area is of the shape of a level-h hexagon ring with all inner hexagon rings (rings of level 0, level 1,…, to level (h–1)) included, we have

$$N_C = 1 + \sum_{k=1}^{h} 6k = 1 + 3h(h+1) \tag{4}$$

In OBP, two center nodes require one vertex node for the purpose of relaying the broadcast packet. We thus have

$$N_V = \sum_{k=1}^{h} 6k/2 = 3h(h+1)/2 \tag{5}$$

Since T_A is the summation of all hexagon areas. We have

$$T_A = N_C (3\sqrt{3} R^2 / 2) \tag{6}$$

With Eqs. (3), (4), (5), and (6), if h is large enough, the transmission efficiency upper bound η_{OBP} of OBP can be derived as follows.

$$\eta_{OBP} = \lim_{h\to\infty} \frac{T_A}{N_T \pi R^2} = \frac{\sqrt{3}}{\pi} \approx 0.55 \tag{7}$$

As shown in [7], the theoretical upper bound η_U of transmission efficiency is 0.61. We have that OBP approximates the theoretical upper bound of transmission efficiency by a ratio of $\eta_{OBP}/\eta_U \approx 90\%$.

V. Performance Comparison

Since OBP is a geometry-based protocol, in this section we compare its performance with that of OFP, the geometry-based protocol with the highest transmission efficiency so far. First, we compare the protocols by analysis in terms of the upper bound of the number of transmissions for broadcasting a packet. Since OBP and OFP are hexagon based approaches, we evaluate them with the assumption that the entire network area is of the shape of a hexagon ring with all inner rings included. In Fig. 9, we show the number of required transmissions for the 2-, 3-, 4-, and 5-level hexagon rings with all inner rings included. The results show that OBP requires fewer transmissions than OFP. This is because OFP requires all vertex nodes to retransmit the broadcast packet, while OBP requires all center nodes plus specific vertex nodes to transmit the packet. The fact that OFP has transmission efficiency of 0.41 and OBP has transmission efficiency of 0.55 also accounts for the results.

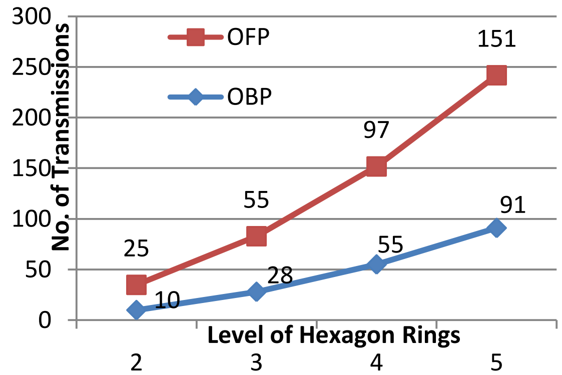

Figure 9. Comparisons of required transmissions for OFP and OBP

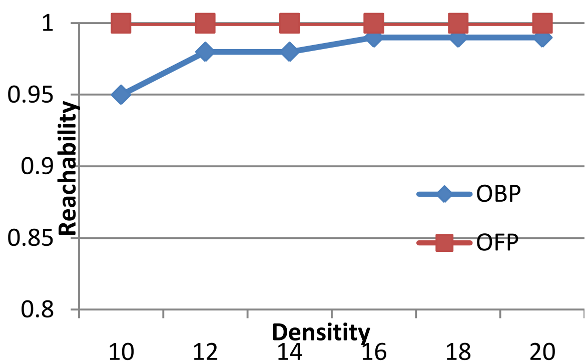

Figure 10. Reachability of OFP and OBP for various node densities

Second, we compare by simulation experiments the protocols' *reachability*, the ratio of the number of the nodes receiving the packet over the total number of reachable nodes, for different node densities. In the simulation, we assume the entire network area is a level-3 hexagon ring with all inner rings included, and assume nodes are uniformly deployed with different densities from $10/R^2$ (nodes per transmission area), $12/R^2$,…, to $20/R^2$. We also assume that nodes exchange location information to decide the best node responsible for rebroadcasting. As shown in Fig. 10, OFP is better than OBP in terms of reachability. The reachability of OFP is 100% for all node densities, while the reachability of OBP is larger than 95% for all node densities, and approximates 99% for the $16/R^2$, $18/R^2$, and $20/R^2$ densities. Theoretically, both protocols have 100% reachability when the node density is sufficiently high. However, when the node density is low, retransmitting nodes may be away from center locations or vertex locations. Therefore, the network area may not be fully covered for some cases. This accounts for the reason why OBP does not maintain 100% reachability for all cases. Since OFP has more retransmitting nodes, the reachability is still 100% even for low node density.

VI. Conclusion

We have proposed an optimized broadcast protocol (OBP) for the wireless network to disseminate a packet throughout the network. The key idea of OBP is to select nodes based on a hexagon ring pattern to minimize the number of retransmissions for better transmission efficiency. The analysis result shows that OBP's transmission efficiency is over 90% of the theoretical upper bound. However, we have observed the OBP may fail to reach all nodes in networks of low node densities. Fortunately, we have an adaptive solution shown below to solve the problem. We make the source node set adaptively the hexagon side length to be a ratio α, $0<\alpha\leq 1$, of the transmission range R according to the node density. When a node finds that the node density is low, it sets a small α value. On the other hand, a node sets a large α value when it detects node density is high. We can easily see that a smaller α value causes more retransmitting nodes, which in turn lead to higher reachability. In this way, OBP can keep high reachability and high transmission efficiency at the same time. In the future, we plan to investigate how to measure the node density accurately and to investigate the relationship between the node density and the value of α to render OBP with the best performance.

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