POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://dergipark.org.tr/politeknik

A novel hypercube-based approach to overlay design algorithms on topic distribution networks

Hiperküp tabanlı konu dağıtım ağlarında yeni bir katman tasarım algoritması

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Yumuşak S., Layazalı S., Öztoprak K., Hassanpour R., "A novel hypercube-based approach to overlay design algorithms on topic distribution networks", ***Journal of Polytechnic***, 25(4): 1535-1552, (2022).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.823124

A Novel Hypercube-based Approach to Overlay Design Algorithms on Topic Distribution Networks

Hiperküp Tabanlı Konu Dağıtım Ağlarında Yeni Bir Katman Tasarım Algoritması

Highlights

- *improved average/maximum node degree for a Pub/Sub Network*
- *Hypercube based Overlay Design Algorithm*

Graphical Abstract

As it is illustrated in Figure 1, the overall diameter of the Hypercube-ODA algorithm is at most at 10.

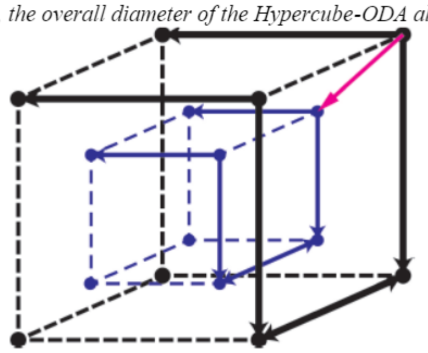

Figure. An Overview of Simple pub/sub Network Using Hypercube ODA Algorithm

Aim

Designing an efficient overlay design algorithm for pub/sub networks

Design & Methodology

Overlay Design methodology for a pub/sub network is generated with an Hypercube approach.

Originality

In the literature there is no Hypercube-based approach Overlay Design Algorithm, which is compared to Greedy Merge, CD-ODA, CD-ODA-I, CD-ODA-II, 2D-ODA, TD-CD- ODA

Findings

Hypercube-based approach Overlay Design Algorithm performs better on generating a lower average node degree.

Conclusion

The proposed study presents a novel approach on generating an Overlay Design for a pub/sub network, which outperforms existing algorithms.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

A Novel Hypercube-based Approach to Overlay Design Algorithms on Topic Distribution Networks

Research Article / Araştırma Makalesi

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(Received : 08.11.2020 ; Accepted : 02.06.2021 ; Erken Görünüm/Early View : 06.07.2021)

ABSTRACT

Data communication in peer-to-peer (P2P) network requires a fine-grained optimization for memory and processing to lower the total energy consumption. When the concept of Publish/subscribe (Pub/Sub) systems were used as a communication tool in a P2P network, the network required additional optimization algorithms to reduce the complexity. The major difficulty for such networks was creating an overlay design algorithm (ODA) to define the communication patterns. Although some ODAs may perform worse on a high-scale, some may have better average/maximum node degrees. Based on the experimentation and previous works, this study designed an algorithm called the Hypercube-ODA, which reduces the average/maximum node degree for a topic connected Pub/Sub network. The Hypercube-ODA algorithm creates the overlay network by creating random cubes within the network and arranging the nodes with the cubes they belong to. In this paper, the details of the proposed Hypercube algorithm were presented and its performance was compared with the existing ODAs. Results from the experiments indicate that the proposed method outperforms other ODA methods in terms of lower average node degree (lowering the average node degree by up to 60%).

Keywords: Peer-to-peer networks, publisher/subscriber systems, overlay network diameter, maximum node degree.

Hiperküp Tabanlı Konu Dağıtım Ağlarında Yeni Bir Katman Tasarım Algoritması

ÖZ

Peer-to-peer (P2P) ağda veri iletişimi, toplam enerji tüketimini azaltmak için bellek ve işleme için ayrıntılı bir optimizasyon gerektirir. Yayınlama / abone olma (Pub / Sub) sistemleri kavramı bir P2P ağında bir iletişim aracı olarak kullanıldığında, ağ karmaşıklığını azaltmak için ek optimizasyon algoritmaları gerektirmektedir. Bu tür ağlar için en büyük zorluk, iletişim modellerini tanımlamak için bir katman tasarım algoritması (ODA) oluşturmaktı. Bazı ODA'lar yüksek ölçekte daha kötü performans gösterse de, bazıları daha iyi ortalama / maksimum düğüm derecelerine sahip olabilir. Deney ve önceki çalışmalara dayanarak, bu çalışmada, Pub / Sub ağına bağlı bir konu için ortalama / maksimum düğüm derecesini azaltan Hypercube ODA adı verilen bir algoritma tasarlandı. Hypercube-ODA algoritması katman ağını yaratmak için rastlantısal küp yapıları kullanarak, küp komşuluklarının düzenlenmesi ile ağı oluşturur. Bu çalışmada, önerilen Hypercube algoritmasının ayrıntıları sunuldu ve performansı mevcut ODA'lar ile karşılaştırıldı. Deneylerden elde edilen sonuçlar, önerilen yöntemin daha düşük ortalama düğüm derecesi açısından diğer ODA yöntemlerinden daha iyi performans gösterdiğini göstermektedir (ortalama düğüm derecesinin %60'a kadar iyileştirildiği gözlemlenmiştir).

Anahtar Kelimeler: Peer-to-peer ağ, publisher/subscriber sistemler, overlay network, maximum node degree.

1. INTRODUCTION

Publish/subscribe (pub/sub) systems were first designed as a client/server or broker-based communication paradigm. The application of pub/sub communications in P2P networks provides a non-centralized communication, storage, processing, and bandwidth for topic/message passing networks. During P2P network implementation, pub/sub networks allow participants to subscribe to topics and get informed about updates in a distributed manner. In such pub/sub networks, the scalability and efficiency of the network become a challenging issue [1][2] in addition to the capacity of the overlay networks[3]. Hence, there is a need to resolve issues related to the overlay design of the network and the stabilization of such networks [4]. Consequently, this study focused on developing algorithms to create an overlay design.

In P2P networks, three major issues such as the maximum node degree, average node degree, and network diameter need to be optimized for network efficiency.

As described in [5], a topic-connected overlay network requires a well-defined method to optimize the overlay diameter (maximum number of edges required to connect two nodes in the network). In addition to this, it is commonly accepted that minimizing energy

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consumption especially in wireless and mobile networks is a critical requirement [6][7]. Previously, [8] proposed TD-CD-ODA for creating overlay networks with the shortest running time. The algorithm improves the network maximum node degree and provides fast network construction, which means that the energy consumption of the node with maximum node degree would be less than that of the node provided by any other algorithm. Energy consumption in a network plays a vital role in the network efficiency. Therefore, constructing a network with optimized energy consumption can improve node functionality and lifetime. This important feature demonstrates the suitability of the proposed method for highly dynamic networks where the changes in topology are very frequent. The novelty of the proposed approach is on reducing the average node degrees while keeping the running time of the algorithm similar to other approaches. In this study, TD-CD-ODA was further extended by introducing a new topological structure and an algorithm to develop the proposed structure. The performance of the newly proposed structure in a comparative way based on maximum/average node degrees for different numbers of nodes, topics, and subscription size.

As the main contribution of this study, it presents a novel method for designing overlay networks in a more efficient way (in average node degree). Previously, [8] proposed TD-CD-ODA for creating overlay networks with the shortest running time. The algorithm improves the network maximum node degree and provides fast network construction, which means that the energy consumption of the node with maximum node degree would be less than that of the node provided by any other algorithm. Energy consumption in a network plays a vital role in the network efficiency. Therefore, constructing a network with optimized energy consumption can improve node functionality and lifetime. This important feature demonstrates the suitability of the proposed method for highly dynamic networks where the changes in topology are very frequent.

This paper was organized as follows: Section 2 provides an overview of related studies in a comparative manner, section 3 presents details of the proposed method for this study and provides the numerical results from the experiments carried out, and section 4 presents the conclusions drawn from the study.

2. RELATED WORK

The internet has significantly reshaped the distribution systems, which comprises many entities with constantly changing behaviors. The constraints stemming from such dynamic systems have increased the demand for loosely coupled approaches that improve flexibility and scalability [9] [10]. Pub/sub systems have attracted a lot of attention due to their loosely coupled communication methods [11] [12] [13] [14] [15] [16]. Generally, subscribers' express interest in events that occur in an environment that is independent of the publishers. In pub/sub systems, publishers who are aware of the attendance of subscribers, broadcast information pertaining to a variety of events throughout the system by assigning a specific value from a set of well-defined values. Then, subscribers who have announced their topics of interest through proper subscriptions are informed about matching events (messages). Subsequently, these events are delivered to the relevant subscribers [17]. The development of a broker-based pub/sub system provides a proper view of the system, which leads to easier implementation of matching algorithms. However, these systems fail to comply with the scalability requirements when the number of publishers and subscribers grows. Therefore, a decentralized pub/sub topology is more suitable for providing effective matching while the P2P model is a suitable architecture for establishing large-scale distributed systems [18] with fault tolerance.

Generally, distributed solutions are utilized in topic-based systems [19] while in content-based systems, messages are either multicast according to the routing trees methods, or the concept of rendezvous is used to guarantee that all the events and subscriptions are included in the system [20] [9] [21] [22]. Furthermore, a number of application designers endeavor to combine both content-based and topic-based pub/sub systems [23] [24]. The topic-based system is accomplished in a decentralized manner by utilizing a distributed hash table as performed by Triantafillou et al. [17].

Based on different perspectives such as cost and average node degree, pub/sub algorithms were examined in different studies. For example, Chen et al. [25] highlighted the problems of existing pub/sub algorithms in three items: (i) high runtime costs, (ii) reliance on knowledge about the whole overlay and centralized management, and (iii) non-incremental overlay design requiring to start from the scratch. They proposed to allow dynamic joins to form multiple topic-connected overlays (TCO). The main idea was to partition the overlays into smaller segments. The results from the study showed a fair trade-off between the run-time efficiency and the maximum node number. However, a detailed comparison with currently available TCO was not included. Additionally, in terms of the cost perspective Cao et al. [26] carried out a study to reduce the communication costs of XML delivery systems using the location aware methods to construct the overlay network. This idea involved building overlay networks by connecting the nodes within different networks together as proposed in [27][28]. They also proposed a message aggregation method to reduce the number of exchanged messages. Results from the study reported that the end-to-end communication delay decreased by 64%. As a cost reducing approach, Zhao et al. [29] worked on dynamic environments. They considered handling dynamism in message passing and communication with high churn in such environments. A cost-driven re-configurable process was proposed by considering the locality of the brokers. By utilizing the localization aware dissemination, the notification delay was reduced by 30% and the reconfiguration cost was reduced by 80%. On the other hand, to decrease the average node degree, Havet et al [30] performed a study on forming a hypergraph by following the node clustering approach. While connecting the nodes, they did not consider node's topic interest and its contribution with other nodes based on their subscriptions. In addition to Havet et al [30]'s approach, the current study benefits from the topic interest which helps to decrease the average node degree dramatically.

In relation with the current study, in topic distribution networks, ODAs were used to optimize network efficiency by defining the relations between nodes and topics. Greedy merge algorithm [20] is the basic algorithm used to work on the nodes interested in a topic. This algorithm can be defined as follows: Suppose that G is an overlay network, and the essential prerequisite needed to solve problem (1) is to ensure topic connectivity where a sub-graph connects all nodes interested in topic m. Chockler et al. introduced the topic-connectivity concept and the minimum topic-connected overlay problem. They provided an approximated solution called the Greedy Merge (GM) algorithm for problems with the minimum number of links. GM algorithm begins with the overlay network G= (N,φ). For each topic m∈M there are

$$\sum_{m\in M} |\{n: I(n,m) = 1\ | \quad (1)$$

individual topic connected components of G. The algorithm continues by connecting two nodes at each repetition until the resulting overlay comprises maximally one topic connected component for each $m\in M$. The two nodes connected during each repetition are those that have the greatest numberof topics in common. For each new pair of nodes such as (n; w) that is connected to the overlay network,$M(n,w)\subseteq M$ is considered as a collection of topics $m\in I(n;m)\cap I(w;m)$. Moreover, these nodes are associated with two distinct numbers of topic connected components [20] [31] [32] [18]. For the Constant Diameter Overlay Design Algorithm (CD-ODA) [32], [18], the algorithm starts with an overlay described in the GM algorithm. At each repetition, a node with the maximum number of neighbors is selected. The number of neighbors for node z is equal to:

$$Q_z = |\{n \in N | \exists m \in M; I(n,m) = I(z,m) = 1\}| \quad (2)$$

Once node z is connected to its neighbors, all topics subscribed by node z would be emitted from the set of topics. According to [18][33] three new algorithms called; the Constant Diameter Overlay Design Algorithm I (CD-ODA-I), the Constant Diameter Overlay Design Algorithm II (CD-ODA II), and the 2 Diameter Overlay Design Algorithm (2D-ODA) were presented. In the Constant Diameter Overlay Design Algorithm I (CD-ODA-I) [18] , the algorithm starts with an overlay defined above as $G= (N,\varphi)$. At each repetition of CD-ODA-I, a node with maximum weight neighbors is selected. The weight of the node z can be calculated by the following formula:

$$W_z = \sum_{m\in M} |\{n \in N | I(n,m) = I(z,m) = 1\}| \quad (3)$$

Similar to the CD-ODA algorithms, once a node with maximum weight neighbor is connected to its neighbors, all topics subscribed by that node would be emitted from the set of topics. In the Constant Diameter ODA II (CD-ODA- II) [18] the algorithm starts with the overlay network $G= (N,\varphi)$.At each iteration, a node with maximum node density d_z, is selected. The node density of a node z,d_z is given by

$$d_z = \frac{\sum_{m\in M} |\{n\in N | I(n,m)=I(z,m)=1\}|}{|\{n\in N | \exists m\in M; I(n,m)=I(z,m)=1\}|} \quad (4)$$

Note that $d_z=W_z/Q_z$. An edge would be added between a node z with maximum node density and all of its neighbors. Finally, all topics belonging to the node interest subscription, would be emitted from the set of topics. In this work, the problems associated with optimizing both the average degree and diameter low in topic-connected pub/sub overlay network design were tackled.

2.1. Decentralized P2P-based Pub/Sub Overlay Algorithms

In P2P networks, the nodes can either take the client or server role. This idea was extended to the design of decentralized pub/sub networks to provide a solution to the high node degree of the broker-based pub/sub networks. The broker-based architecture of the pub/sub networks used brokers to connect subscribers and publishers. Therefore, brokers play a central role in connecting the publishers and the subscribers, and they suffer from the high node degree problem. P2P network structure was used in topic-based pub/sub overlay networks where $n\in N$ nodes announced their interest in topic t. In this architecture, subgraphs corresponding to each topic were overlayed on the physical network resulting in a decentralized architecture. Hence, the nodes subscribed to any specific topic did not have to rely on any specific intermediate nodes for delivering messages. In contrast to the centralized networks with a constant diameter, the P2P network may be created with large diameters which can degrade the performance of the network [20], for instance in reduced routing efficiency [34] [35] [36].

The group of Constant Diameter ODAs (CD-ODA) [18] established a topic-based pub/sub network in which each overlay network diameter was assumed to be limited to a fixed number. Since these algorithms construct a network based on the star topology, the diameter of each overlay network would beat most 2. Compared with the GM algorithm, these algorithms have a considerably lower diameter. However, the number of edges needed to connect the nodes was higher than that of the GM algorithm. In addition, these four algorithms experience a high rate of maximum-node-degree. The CD-ODA I algorithm starts with an overlay network defined as $G(N,E)$. At each repetition, a node with the highest number of weighted neighbors is selected. The weighted number of neighbors can be defined as:

$$W_u = \sum_{m\in M} |\{n \in N | int(n,m) = int(u,m) = 1\}| \quad (5)$$

where *int(u,m)*indicates that the node u is interested in topic m. Then the node with the highest weighted neighbors for topic m is connected to all the nodes interested in that topic. Then the algorithm proceeds with the next topic and it creates an overlay for each topic in this way. The main drawback of the algorithm is that a node interested in many topics would become the center for all the overlay networks and as a result obtain a high maximum node degree. The CD-ODA I algorithm is extended in CD-ODA II where the node with maximum connection density d_u is selected during each repetition. The connection density is defined as the weighted neighbors normalized by the number of nodes interested in at least one of its interested topics or W_u/N_u. If there exists overlapping between the edges from different overlay networks, N_u becomes smaller while W_u does not change. Hence, the normalization causes the nodes with overlapping edges from different overlays to have a higher chance to be selected. This normalization tends to select nodes that are interested in many topics, resulting in many overlapping edges as the center of topics. This results in even denser overlay networks and higher maximum node degrees.

This algorithm family was further optimized with the introduction of a 2-Diameter Overlay Design Algorithm (2D-ODA) [37]. It is described as:

"*The 2D-ODA starts with the overlay network G(V,E) and topic set M. At each iteration of the2D-ODA, for each node u a topic m_k∈M and int(u,m_k) = 1 is chosen such that topic m_k has the maximum topic density at node u. The topic density td(u,m_k) of a node u for a topic m_k where int(u,m_k) = 1 on an overlay network G(V,E)*" [37] is given by:

$$td(u, m_k) = \frac{\sum_{m\in M} |\{v\in V | int(v,m) = int(u,m) = 1\}|}{|\{v\in V | int(v,m_k) = int(u,m_k) = 1, (u,v) \notin E\}|} \quad (6)$$

Subsequently, the node with the highest maximum topic density for each topic was found and designated as the center of the overlay for that topic. The algorithm proceeds with remaining topics until all topics are processed. Like CD-ODA II, 2D-ODA algorithm selects the nodes which maximize the overlapping of the edges from different overlays, hence, minimizing the total number of edges in the network. However, the algorithm fails to consider the maximum node degree of the network and does not attempt to create a fully decentralized network. Since all these algorithms construct a network based on the star topology, the diameter of the network would be at most (2). In other words, all nodes deployed over the network, require at most 2 connections to forward, or receive any subscribed messages. Compared to the GM algorithm, these algorithms have a considerably lower diameter. However, the number of edges needed to connect the nodes was higher than of the GM algorithm. In addition, these four algorithms suffer from a high rate of maximum node degree.

2.2 Publish/Subscribe ChallengesThere are three main challenges to be handled to build an effective pub/sub system which includes:

- expression of the interest to the topics by the subscribers,
- organization of the notification service to deliver interests to topics,
- delivery of the messages to subscribers by publishers.

These states are connected strongly, and their contribution can affect the system performance. For instance, a rudimentary subscription algorithm may improve the functionality of multicasting; however, it facilitates poor expression ability for subscribers to announce their interested topics [17].

The architecture of pub/sub systems generally can be divided into client-server groups and P2P [9]. In client server architectures, servers are providers of the information (publishers), and the clients are the subscribers. To de-couple clients and servers for better performance, intermediate nodes called brokers were introduced. These architectures, therefore, are referred to as broker-based architectures. In P2P architectures, each node performs as either subscribers or publishers or both. In fact, in the P2P paradigm, all nodes can operate in a variety of roles such as a publisher, subscriber, root or internal node of a multicast tree, and in play a combination of these roles. The P2P architecture is also called a decentralized architecture. It is desirable for a typical pub/sub system to hold two principal characteristics of P2P networks: i) scalability, and ii) fault tolerance/reliability. In the following subsections, both architectures were briefly introduced.

3. PROPOSED SOLUTIONS

3.1 Preliminary Study: The Topic Distribution Constant Diameter Overlay Design Algorithm (TD-CD-ODA)

The TD-CD-ODA [8] was initially created to minimize the maximum node degree with a lower-diameter. The algorithm initiates with an overlay network G(N,φ). Then, at each iteration, it finds a node z with minimum topic distribution t_z.

For each topic m∈M subscribed by node z, calculate the total number of interested in m (Denote as n_m):

$$TopicDistribution_{(node\ z)} = \frac{n_m}{subscription\ size_{(node\ z)}} \quad (7)$$

The algorithm is described briefly in algorithm 1, which has a more detailed view in [8].

Algorithm 1 TD-CD-ODA Summarized View

```
for each topic do
    // calculate the topic distribution for each node as:
    Find minimum t_z for each node
    Connect nodes to nodes with topic interest = 1
    Remove topics which have topic interest = 1
```

In this study, TD-CD-ODA was further extended by introducing a new topological structure and an algorithm to develop the proposed structure. The performance of the newly proposed structure in a comparative way based on maximum/average node degrees for different numbers of nodes, topics, and subscription size.

3.2 A Novel Hypercube Topic-Based Pub/Sub Algorithm

Previously, [8] proposed TD-CD-ODA for creating overlay networks with the shortest running time. The algorithm improves the network maximum node degree and provides fast network construction, which means that the energy consumption of the node with maximum node degree would be less than that of the node provided by any other algorithm. Energy consumption in a network plays a vital role in the network efficiency. Therefore, constructing a network with optimized energy consumption can improve node functionality and lifetime. This important feature demonstrates the suitability of the proposed method for highly dynamic networks where the changes in topology are very frequent. The novelty of the proposed approach is on reducing the average node degrees while keeping the running time of the algorithm similar to other approaches.

In this section, the Hypercube-ODA pub/sub algorithm for the Low-Diameter-TCO problem was introduced. It provides an overlay network with a lower diameter, average node degrees, and similar maximum node degrees compared to previously developed ODAs.

Hypercube-ODA starts with an overlay network G(N, E) and a topic set M. All nodes were initially divided into random cubes. For a network with 4n nodes, n/2 cubes are needed to establish the overlay. Each node can be identified through a node id parameter representing the group that a node belongs to.

Additionally, each node belonging to specific groups were also divided into two different layers: the inner and outer layer of cube I (each cube has two different layers (inner and outer)). For example node(i,j) belongs to cube number i and layer j. If j= 0, the considered node is located in the inner layer. If j= 1 the nodes belong to the outer layer of cube i. Hence, there are 3 types of connections.

Hypercube-ODA starts with an overlay network *G*(*N*, *E*) and a topic set M. All nodes are initially divided into random cubes. For such a network with 4n nodes, n/2 cubes are needed to establish the overlay. Each node can be identified through node_id parameter representing the group that a node belongs to. Additionally, each node belonging to specific groups are also divided into two different layer: inner and outer layer of cube i (each cube has two different layers (inner and outer)). For example: $node(i, j)$ belongs to cube number *i* and layer *j*. If j = 0, the considered node is located in inner layer. If j = 1 the nodes belong to outer layer of cube *i*. Hence there are 3 type of connections.

- Routing Type 1: Connects two nodes that are in the same cube and same layer.
- Routing Type 2: Connects two nodes that are in the same cube's opposite layers.
- Routing Type 3: Connects two nodes with different cube id, i.e. those nodes belonging to different nodes.

In order to construct the overlay, at first, nodes belonging to the same cube and the same layer were connected (according to the algorithm provided for routing 1). At each iteration, all nodes (in cube i and layer j) interested in topic t were connected.

In the following steps, routing 2 considers only two pair of nodes which belong to the same cube but different layers. At each iteration, two nodes with the most common topics were connected until all nodes (in cube i) for each topic were connected. In the end, nodes in different cubes were connected through routing 3 part in the algorithm. This routing follows the same procedure in routing 2, but only two pair of nodes in different cubes were considered.

At each repetition of Hypercube-ODA, a node z which has the max. weighted neighbors was selected. The neighbor weight of node z belonging to Cube i and Layer j is equal to:

$$W_z = \sum_{m \in M} |\{n_{i,j} \in N | I(n_{(i,j)}, m) = I(z_{(a,b)}, m) = 1\}| \qquad (8)$$

Where (i, j) and (a, b) represent the cube_id and layer of a specific node. For example, to connect a node based on routing type 1, where nodes with the same cube_id and layer are considered, the quantity of i,j are equal to a,b respectively. Finally, all topics, belonging to the node's interest subscription, would be emitted from the set of topics. It should be mentioned that the meaning of neighbors according to the type of connections explained above can be varied through implementation.

Algorithm 2 Hypercube-based Algorithm Implementation

M ← Set of all topics
N ← Set of all nodes
while T is NOT empty **do**
    //**Routing Type 1:**
    For each node u(i;j) calculate number of nodes z(i;j) such that there exists a topic m ∈ M and I(u(i;j);m) = I(z(i;j);m) = 1. Denote this number by n_u.
    Find node u with maximum n_u.
    Put an edge between node u and every node z if there exists a topic m∈M with I(u(i;j);m) = I(z(i;j);m) = 1
    Remove all topics m∈M with I(u(i;j);m) = 1.
    //**Routing Type 2:**
    For each node u(i;j), calculate number of nodes such that there exists a topic m ∈ M and I(u(i;j);m) = I(z(i;k);m) = 1. Denote this number by n_u.
    Find node u with maximum n_u.
    Put an edge between node u and every node z which has more topic m ∈ M than other nodes in layer k in common.
    Do until all topics m ∈ M and I(u(i;j);m) = 1, are connected.
    Remove all topics m from M with I(u(i;j);m) = 1.
    //**Routing Type 3:**
    For each node u(i;j), calculate number of nodes if there exists a topic m ∈ M and I(u(i;j);m) = I(z(m;n);m) = 1. Denote this number by n_u.
    Find node u with maximum n_u.
    Put an edge between node u(i;j) and node z(m;n) which has more topic m ∈ M than other nodes in $Cube_m$ in common.
    Do until all topics m ∈ M and I(u(i;j);m) = 1, are connected.
    Remove all topics m from M such that I(u(i;j);m) = 1.
end while

The diameter of the overlay network plays a vital role since it determines the maximum number of links that a publisher or subscriber may have to take. The diameter of each layer with N nodes is 2. However, this value would be at most 5 for nodes in a specific cube. In addition, each node can connect to other nodes belonging to different Cube with only one extra link. As it is illustrated in Figure 1, the overall diameter of the Hypercube-ODA algorithm is at most at 10.

According to routing type 2 and type 3, the node u with maximum weighted neighbors was connected to the nodes belonging to other layers and the cube_id has the most common topics. In addition, for each topic m which I(u(i,j),m) = 1 only one edge is required to connect node u(i,j) and other node in different layers or cubes based on the average degree. The Hypercube-ODA was implemented and experimented by varying the number of nodes, number of topics, and subscription sizes. In Tables 1, 3, and 5, Hypercube-ODA experimental results (average node degree, maximum node degree, running time for building the network, average node variance, and maximum node variance) by varying the number of nodes are listed. Additionally, in Tables 2, 4, and 6, the highest (max.) and the lowest (min.) average and maximum node degree values for all random experiments on the Hypercube-ODA are listed.

In the following Sections 3.3, 3.4, and 3.5, comparative experimental results for the proposed Hypercube-ODA method and the previously developed ODA methods are listed.

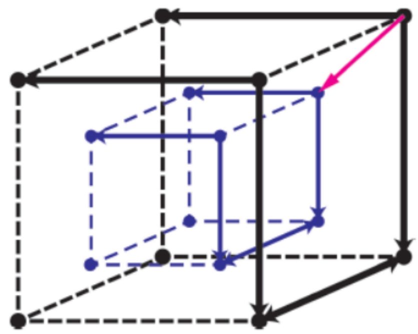

Figure 1. An Overview of Simple pub/sub Network Using Hypercube ODA Algorithm

Table 1. Hypercube-ODA Experimental Results for Varying Number of Nodes

# of Nodes	Avg. Node Degree	Max. Node Degree	Execution Time (ms)	Avg. Node Variance	Max. Node Variance
100	10,20	89	1053	715,69	3,20
250	8,90	179,20	4681	1937,81	9,36
500	8,60	354,90	30628	22510,20	47,09
1000	7,12	695,10	178272	27927,60	102,89
2000	6,87	1397,10	993450	21289	142,09

Table 2. Hypercube-ODA Experimental Node Degree Margins for Varying Number of Nodes

# of Nodes	Min. Avg.	Max. Avg.	Min. Max.	Max. Max.
100	9,97	10,12	85	91
250	8,42	9,25	174	184
500	8,24	8,97	347	372
1000	6,91	7,88	677	715
2000	6,32	7,34	1382	1417

Table 3. Hypercube-ODA Experimental Results for Varying Number of Topics

# of Topics	Avg. Node Degree	Max. Node Degree	Execution Time	Avg. Node Variance	Max. Node Variance
200	7,15	115,40	13921	2755,04	13,84
250	6,91	96,60	22261	2410,05	15,84
300	6,57	83,20	29412	3132,61	12,56
350	6,36	75,80	39717	3518,84	17,76
400	6,23	67,80	47181	3245,60	5,96

Table 4. Hypercube-ODA Experimental Node Degree Margins for Varying Number of Topics

# of Topics	Min. Average	Max. Average	Min. Maximum	Max. Maximum
200	6,94	7,43	107	119
250	6,59	7,29	90	102
300	6,31	7,22	77	90
350	5,96	7,18	69	84
400	5,86	7,06	64	71

Table 5. Hypercube-ODA Experimental Results for Varying Subscription Sizes

Subsc. Size	Avg. Node Degree	Max. Node Degree	Execution Time	Avg. Node Variance	Max. Node Variance
15	6,82	239,40	3898	1124,20	7,04
20	6,35	254,50	2985	1607,25	0,85
25	6,14	254,90	2414	2471,24	0
30	5,87	255	2386	2176,17	0
35	5,69	255	2109	1237,04	0

Table 6. Hypercube-ODA Experimental Node Degree Margins for Varying Subscription Sizes

Subsc. Size	Min. Avg.	Max. Avg.	Min. Max.	Max. Max.
15	6,32	7,16	236	246
20	5,82	6,75	253	255
25	5,31	6,68	255	255
30	5,26	6,04	255	255
35	5,17	5,69	255	255

3.3. Avg. and Max. Node Degree with Varying Number of Nodes

In this section of experiment, quantity of nodes changes between 100 to 2000 and the number of topics and subscription size are kept at 100 and 10 respectively. All nodes subscribe variety of topics randomly. Table 7 compares the algorithms based on the average degree. The average node degree of the overlay reduced for all the algorithms (except TD-CD-ODA) as the size of the nodes grew because more nodes with higher contributions over the network can be found. When the Greedy Merge and Hypercube-ODA were compared, it was found that the Hypercube-ODA algorithm needs 1.21 times more edges than GM maximally (Table 7 and Figure 2). The average node number of TD-CD-ODA decreased as the algorithm chose nodes with lower contributions. Furthermore, the avg. node degree variance values are compared in Table 8 and Figure 3.

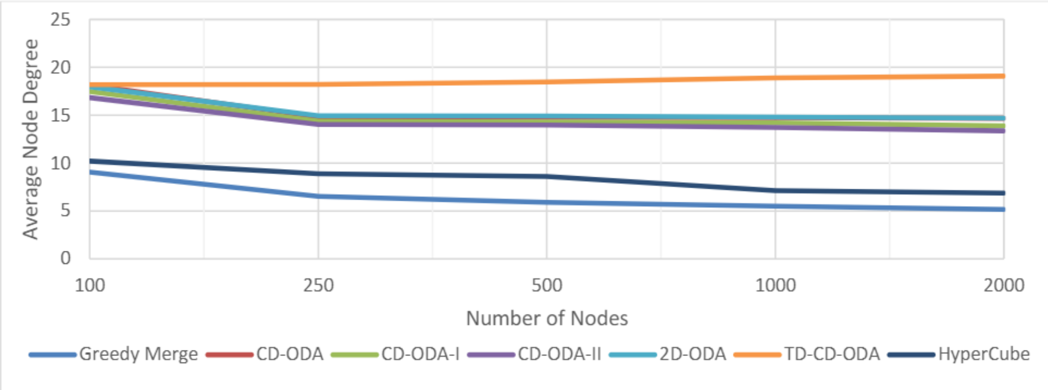

Figure 2. Avg. Node Degree for Varying Number of Node

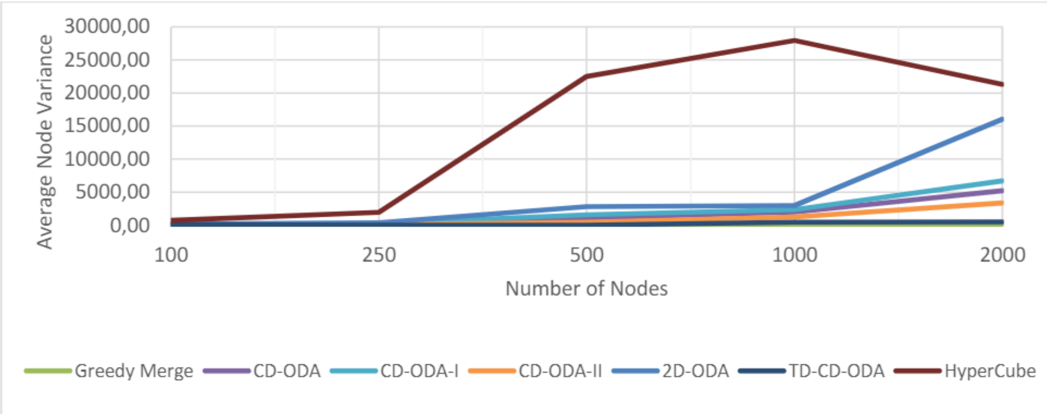

Figure 3. Avg. Node Variance for Varying Number of Nodes

To consider maximum node degree, when additional nodes join through-out the network, the probability of adding nodes with satisfied contribution will grow. Hence, to connect a large number of nodes, low edges are required and as a result, the maximum node degree gets higher (Table 9 and Figure 4). In GM algorithm, sometimes a node can be added to the network, which has a noticeable contribution with the array of nodes. This added node can individually raise the maximum node degree significantly because it connects to a large number of nodes in the form of star topology (Table 9 and Figure 4). Although the GM algorithm provides low maximum and average node degrees, the diameter resulting from this algorithm would be high. Furthermore, the max. node degree variance values are compared in Table 10 and Figure 5.

3.4. Avg. and Max. Node Degree with Varying Number of Topics

In the second part of the experiment, the number of nodes and subscription size was kept at 250 and 10 respectively. Similar to the previous experiment, all nodes were interested in a random topic. For this part of the experiment, conditions were also the same as those considered in the studies [20], [32], [18] and [33]. The average degree reduced for the algorithms when the number of topics increased because the edges will have weak contributions and the number of nodes without any neighbor increases (Table11 and Figure 6). Furthermore, the avg. node degree variance values are compared in Table 12 and Figure 7.

As the node number rises, the network will encounter two completely distinct situations. Firstly, the contribution among the nodes will decrease, hence, more edges will be needed to build the overlay. Moreover, the probability of the nodes without any neighbors will also rise. The second condition affects the maximum degree of all constant diameter and Hypercube algorithms. When the topic sets grow, the maximum node degree provided by a constant diameter algorithm and Hypercube will reduce even though the GM algorithm has been impressed by situation one. Therefore, the maximum node degree increased from 28 to 34 (Table 13 and Figure 8). Furthermore, the max. node degree variance values are compared in Table 14 and Figure 9.

Table 8. Avg. Node Variance for Varying Number of Nodes

# of Nodes	GM	CD - ODA	CD - ODA-I	CD - ODA-II	2D -ODA	TD-CD-ODA	Hypercube-ODA
100	4,16	125,49	206,76	53,64	160,60	86,49	715,69
250	40,16	67,41	267,84	73,69	381,84	3,36	1937,81
500	81,80	1059,60	1592,21	454,40	2806,40	23,76	22510,20
1000	92,89	1986,61	2361,05	1242,16	2966,64	442,09	27927,60
2000	137,44	5212,21	6712,45	3380,20	16030	505,60	21289

Table 9. Max. Node Degree for Varying Number of Nodes

# of Nodes	G M	CD - ODA	CD - ODA-I	CD - ODA-II	2D - ODA	TD-CD-ODA	Hypercube-ODA
100	18	95	89	89	84	76,1	82
200	21	193	183	170	168	156,9	154
500	23	370	365	341	338	308,7	335
1000	25	738	718	710	677	644,7	650
2000	26	1447	1411	1409	1396	1317	1309

Table 10. Max. Node Variance for Varying Number of Nodes

# of Nodes	G M	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
100	0,89	1,20	9,45	12,81	7,01	0,09	3,20
250	3,24	5,49	13,84	27	41,65	10,29	9,36
500	6,04	17,84	45,45	76,04	53,45	14,81	47,09
1000	5,05	37,65	109,56	214,01	53,64	52,41	102,89
2000	14,56	20,81	328,40	115,36	117,76	182,60	142,09

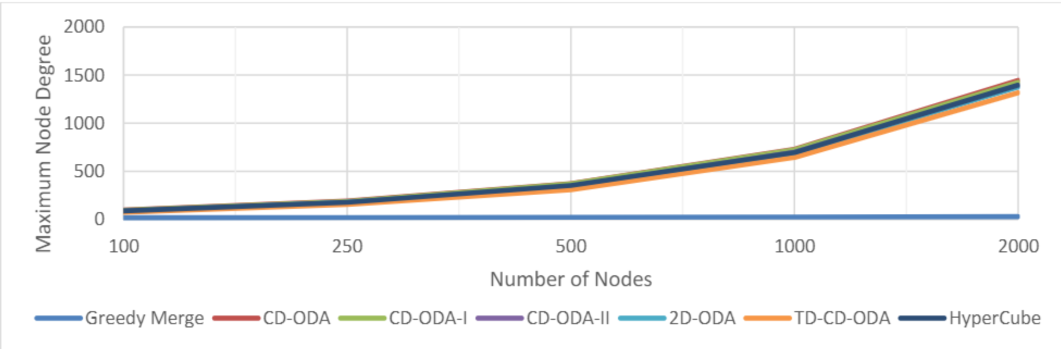

Figure 4. Max. Node Degree for Varying Number of Nodes

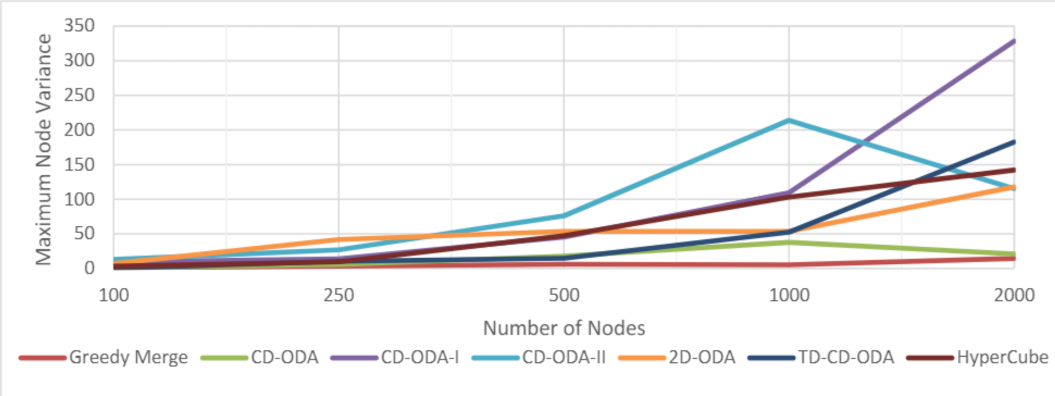

Figure 5. Max. Node Variance for Varying Number of Nodes

Table 11. Avg. Node Degree for Varying Number of Topics

Topics	GM	CD - ODA	CD - ODA-I	CD - ODA-II	2D - ODA	TD-CD-ODA	Hypercube-ODA
200	10.22	16.73	16.27	15.56	16.08	18.09	7.15
250	9.78	16.6	16.25	15.52	15.9	17.79	6.91
300	9.02	16.53	16.21	15.51	15.61	17.49	6.57
350	8.28	16.5	16.19	15.43	15.32	17.18	6.36
400	7.38	16.22	16.05	15.29	14.93	16.81	6.23

Table 12: Average Node Variance for Varying Number of Topics

# of Nodes	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
200	114,01	162,49	146,49	84,16	119,56	46,84	2755,04
250	112,81	249,76	166,69	102,16	11,64	56,16	2410,05
300	130,16	68,16	52,44	61,41	24,81	21,09	3132,61
350	76,6	60,8	128,44	48,76	47,84	51,44	3518,84
400	135,24	87,05	129,6	76,24	77,76	75,25	3245,6

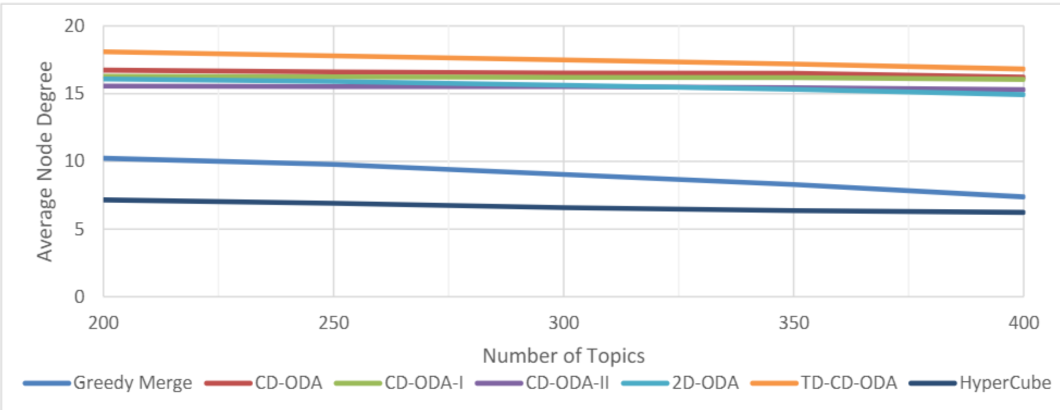

Figure 6. Avg. Node Degree for Varying Number of Topics

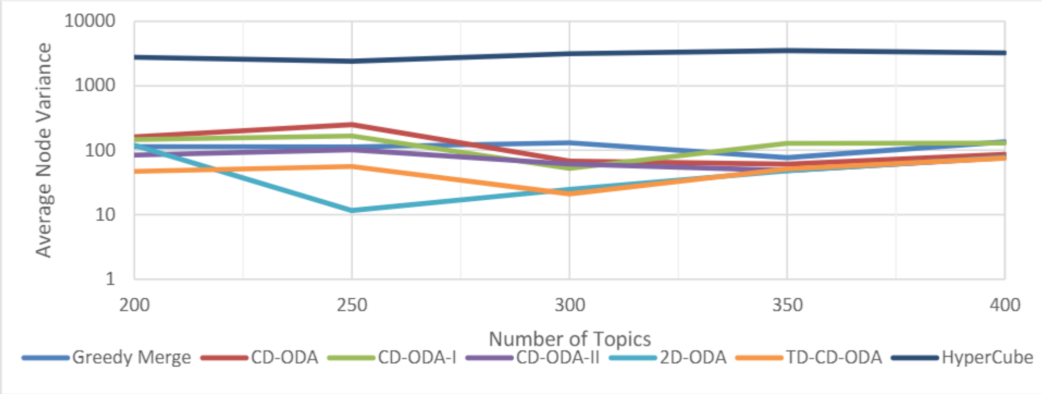

Figure 7. Avg. Node Variance for Varying Number of Topics (Logarithmic Scale)

Table 13: Max. Node Degree for Varying Number of Topics

Topics	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
200	28.3	128	124.2	112.6	91.6	85.9	115.4
250	29.60	107.2	106.4	91.7	66	62.1	96.6
300	30.4	95.2	92.1	78.2	55.7	52.2	83.2
350	33.7	86	83.8	70	47.9	46.5	75.8
400	35	76.2	77	64.3	44	43	67.8

Table 14: Max. Node Variance for Varying Number of Topics

Topics	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
200	5,41	18,8	7,76	21,64	106,04	26,89	13,84
250	3,24	8,36	10,04	22,01	42	16,09	15,84
300	5,44	7,56	10,49	7,96	29,61	0,96	12,56
350	4,81	16,2	9,16	22,8	26,89	1,84	17,76
400	2,4	11,16	14	8,41	15	15	5,96

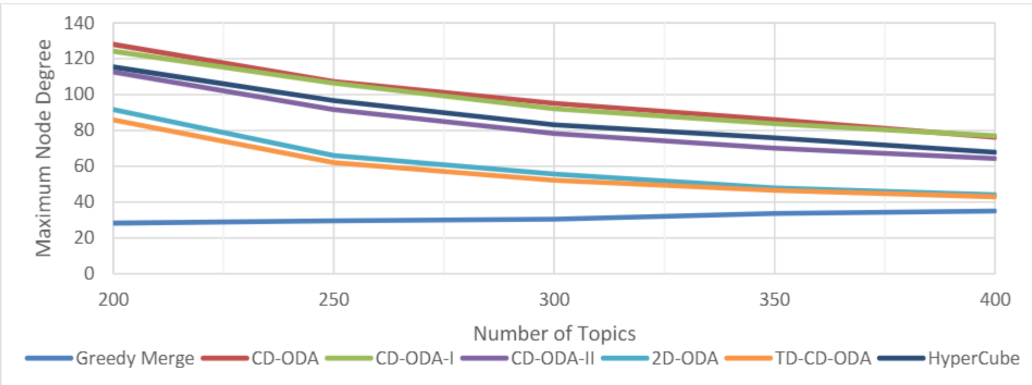

Figure 8. Max. Node Degree for Varying Number of Topics

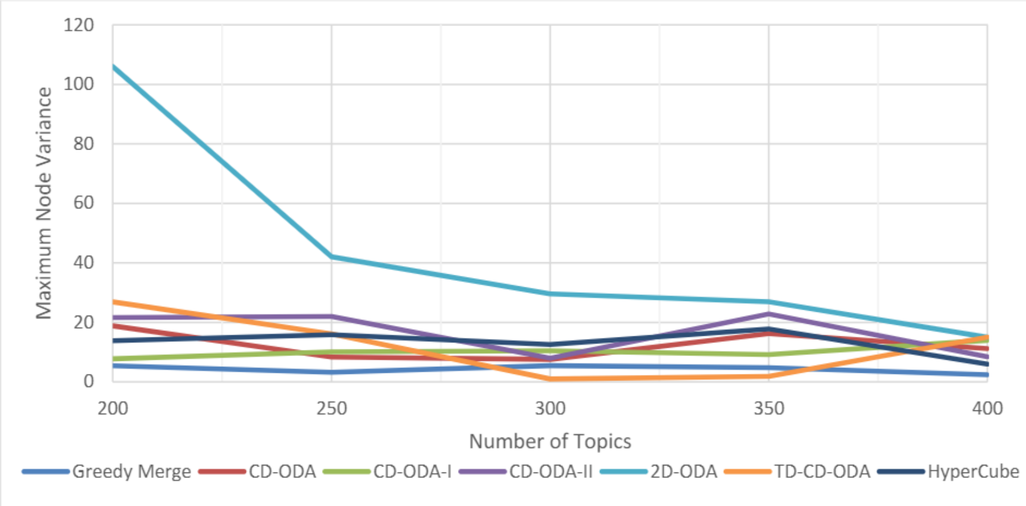

Figure 9. Max. Node Variance for Varying Number of Topics

3.5. Average Node Degree with Varying Subscription

For the third part, the quantity of nodes and topics were fixed at 100 and 250 respectively. The subscription size varied between 35 and 15. Table 15 and Figure 10 demonstrates the average node degree provided by all algorithms. The average degree of all the algorithms (except TD-CD-DA) show a downward trend as the subscription size grows, because, the algorithms can discover the nodes with a satisfied contribution. A comparison of the results showed that the Hypercube-ODA maximally needs 0.06 times more link than the GM (Table 17 and Figure 12). The 2D-ODA improved the CD-ODA-II,CD-ODA and CD-ODA-I on the average as the subs. size increased to 35 (Table 17). As TD-CD-ODA selected nodes that have lower contributions, the average node degree for this algorithm increased from about 24to almost 28. Furthermore, the average node degree variance and maximum node degree variance values are compared in Table 16, Figure 12, Table 18, Figure 13 respectively.

Table 15. Avg. Node Degree for Varying Subscription Size

Subsc. Size	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
15	6,3	16,2	15,35	15,35	16,42	23,58	6,7
20	6,03	14,84	14,31	14,29	15,24	25,71	6,11
25	5,7	13,36	12,65	12,65	13,2	26,96	6
30	5,44	11,8	12,11	12,08	11,59	27,2	5,92
35	5,1	12,45	11,2	11,02	10,9	27,84	5,44

Table 16. Avg. Node Variance for Varying Subscription Size

Subsc. Size	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
15	27,96	1156,16	621,04	566,76	3328,8	108,16	1124,2
20	25,16	2697,69	958,65	934,16	1628,76	0	1607,25
25	14,01	3516,44	1528,29	1261,96	2607,04	0	2471,24
30	20,24	2267,89	1944,85	825,61	1935,64	0	2176,17
35	23,68	2159,92	1115	916,43	2168,59	0	1237,04

Table 17. Maximum Node Degree for Varying Subscription Size

Subsc. Size	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
15	17	247	247	243	244	227,6	246
20	15	255	255	249	251	252,8	252
25	13	255	255	255	255	254,2	255
30	12	255	255	255	255	255	255
35	9	255	255	255	255	255	255

Table 18. Maximum Node Variance for Varying Subscription Size

Subsc. Size	GM	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hypercube-ODA
15	3,16	0,96	9,29	7,25	15,56	0,64	7,04
20	4,81	0	0,44	0,69	0,86	0,01	0,85
25	3,24	0	0	0,09	0	0,49	0
30	2,76	0	0	0	0	0	0
35	2,81	0	0	0	0	0	0

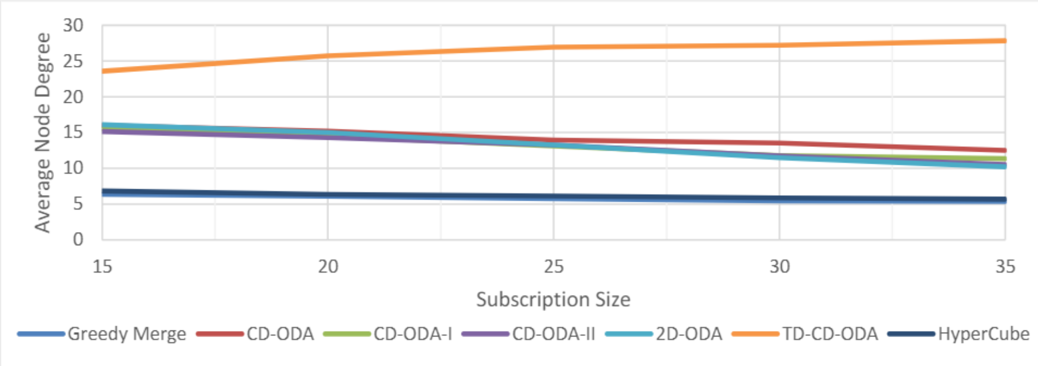

Figure 10. Avg. Node Degree for Varying Subscription Size

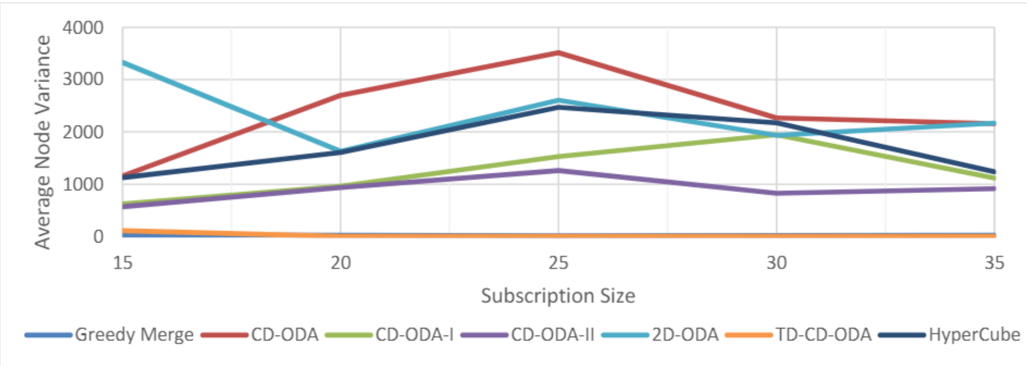

Figure 11. Avg. Node Variance for Varying Subscription Size

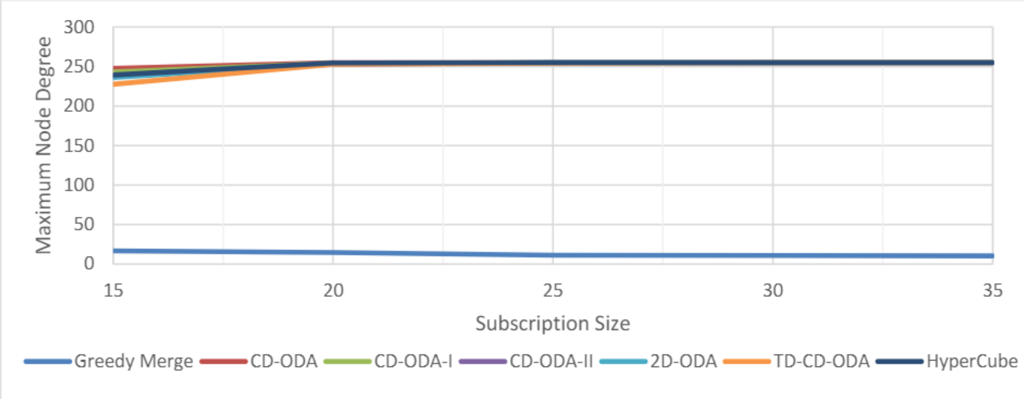

Figure 12. Maximum Node Degree for Varying Subscription Size

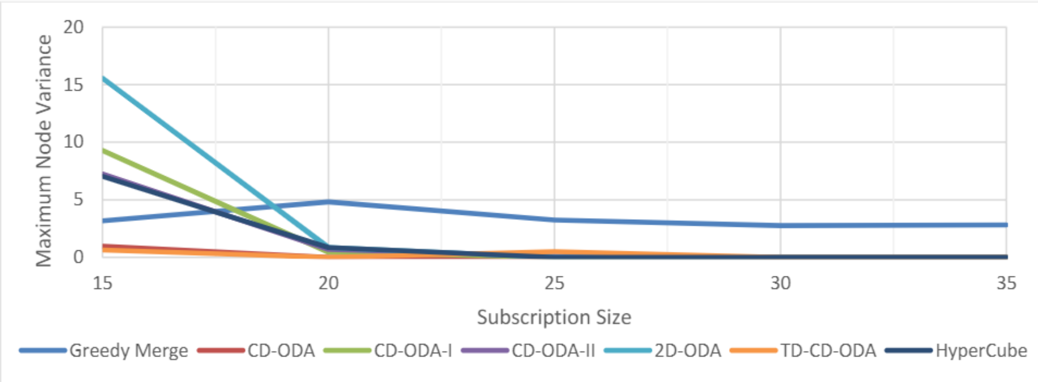

Figure 13. Maximum Node Variance for Varying Subscription Size

On the other hand, by increasing the size of nodes' subscription, the contribution among the node improved. Therefore, the Greedy Merge algorithm can easily discover several pairs of nodes that decreases the total topic connected component. Thus, the max. node degree will decrease as the subcr. size increases. For all of the algorithms with star topology and Hypercube algorithms, the maximum node degree will increase as only nodes were chosen to be the center of many topics in order to be connected with their neighbors (Table 17 and Figure 12).

3.6. Execution Times

The execution times of the algorithms for different number of subscriptions, nodes, and topics are listed in Tables 19, 20, 21 and Figures 14, 15,16 respectively. Although all execution times are more than the previously developed TD-CD-ODA, Hypercube-ODA has similar execution times with the other algorithms.

Table 19. Execution Times for Varying Subscription Sizes

Subsc. Size	Greedy Merge	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hyper Cube
15	3561	1786	3001	4527	2625	67	3898
20	4790	970	1934	2623	3197	52	2985
25	5362	617	1555	2024	4044	45	2414
30	7655	488	1506	1990	5779	44	2386
35	8125	437	1610	1852	6382	38	2109

Table 20. Execution Times for Varying Number of Nodes (Milliseconds)

# of Nodes	Greedy Merge	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hyper-Cube
100	286	616	724	1495	472	29	1053
250	1936	2250	2747	4946	1437	65	4681
500	18981	10454	11041	23989	7289	230	30628
1000	117860	36027	41545	102913	28766	521	178272
2000	895437	126789	162020	274561	85966	896	993450

Table 21. Execution Times for Varying Number of Topics

# of Topics	Greedy Merge	CD-ODA	CD-ODA-I	CD-ODA-II	2D-ODA	TD-CD-ODA	Hyper-Cube
200	2029	9765	10327	23223	2830	199	13921
250	2385	17424	20017	48047	4032	304	22261
300	2404	24658	24457	62032	4963	379	29412
350	2562	33301	36272	102329	5666	514	39717
400	2660	44178	43381	105057	5972	518	47181

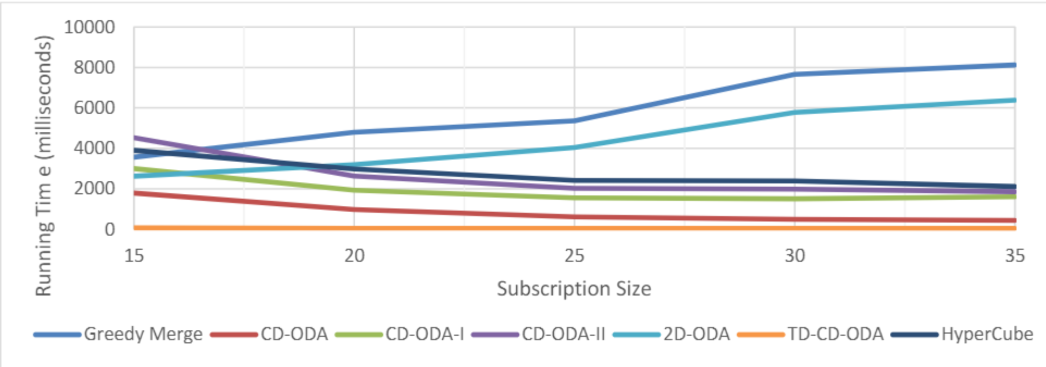

Figure 14. Execution Times for Varying Subscription Sizes

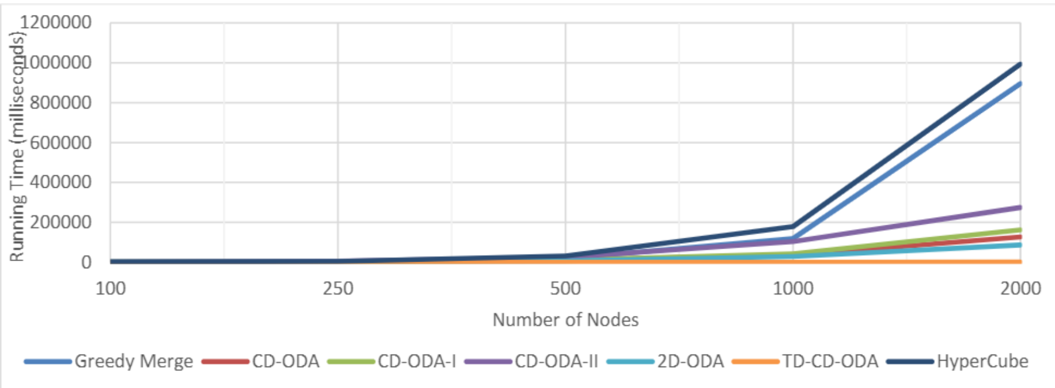

Figure 15: Execution Times for Varying Number of Nodes

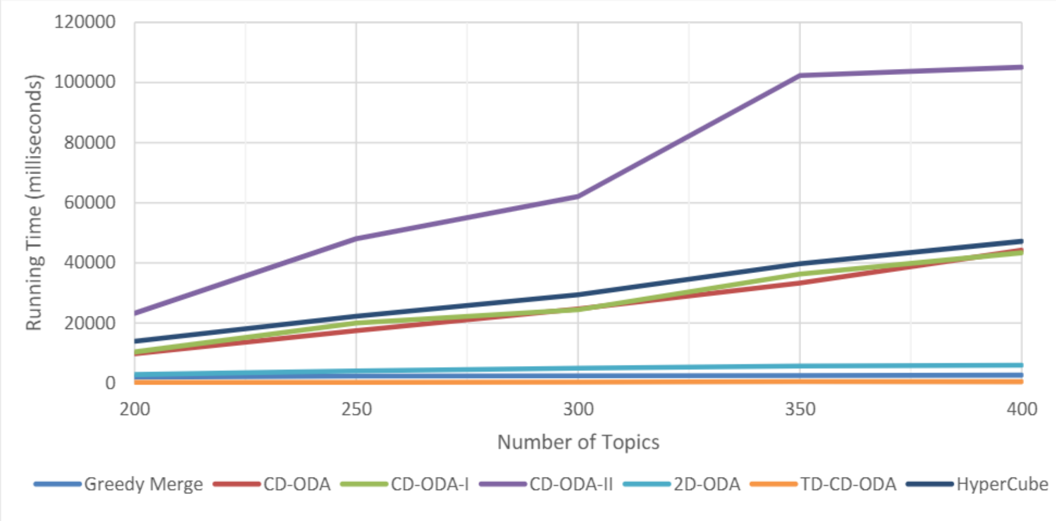

Figure 16: Execution Times for Varying Number of Topics

5.CONCLUSION

In this paper, the topological structure of the newly developed Hypercube-ODA method was presented. Details of the proposed algorithm for creating a Hypercube overlay network given a set of nodes and their interested topics were described. The performance of the proposed algorithm using an intensive set of scenarios against the most used existing methods were analyzed. From these experiments, it was observed that the Hypercube method was able to create overlay networks with lower average node degrees than the GM, although its maximum node degree was not better than the existing methods. This results in faster access to content organized using the Hypercube algorithm. In other words, the Hypercube algorithm connects nodes with satisfied correlation, as the number of connections required to build a network is less than any other algorithm. Due to the bandwidth constraint and the vast amount of energy consumption and resources required for traffic monitoring through each connection, networks with lower average node degree are more ideal for designers.

In the Hypercube algorithm, nodes are initially distributed into random cubes. However, the randomization does not affect the final result since the average node degree or maximum node degree provided by this algorithm would vary in each cube. Nodes located in one cube can be connected with lower number of connections as they can be satisfied with an ideal contribution by their neighbors.

On the other hand, nodes sometimes need more connections to be connected or even stay unconnected in the located cube. But they will be finally connected to other nodes in the opposite layer or even in different cubes (if they have any interest in common).

As a future research direction, a combination of the new algorithm and the previously developed TD-CD-ODA algorithm would be studied to further improve it by reducing the average and maximum node degrees simultaneously. Similarly, it would be good idea to cluster nodes to specific groups in which they have better contributions with themselves based on topic semantics.

ACKNOWLEDGEMENT

This study was supported by KTO Karatay University.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Semih Yumuşak: Analyzed the results, wrote the manuscript.

Sina LAYAZALI: Performed the experiments and created the results. Wrote the manuscript draft.

Kasım ÖZTOPRAK: Reviewed and corrected the manuscript.

Reza HASSANPOUR: Reviewed and corrected the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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