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Dynamic routing protocols for wireless touch networks: a review

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Abstract. Wireless Touch Networks (WTN) have become increasingly important with the emergence of the Internet of Things (IoT) and are regarded as a class of self-organizing networks. This article presents an overview of the construction principles, routing protocols, quality of service parameters, traffic models, and characteristics of WTN. The article also explores the application of dynamic routing protocols for constructing a self-organizing network of autonomous IoT systems. Known dynamic routing protocols for mobile radio networks are reviewed and the advantages and disadvantages of proactive and reactive approaches are discussed.

Keywords: Wireless Touch Networks, Internet of Things, self-organizing networks, dynamic routing protocols, proactive approach, reactive approach

1. Introduction

In recent years, mobile devices have become widespread: cell phones, laptops, smartphones, and tablets. This has opened up new opportunities for the developers of network solutions [63]. One of the areas of development of network technologies for mobile devices is the Internet of Things.

The current direction of development of communication networks is the concept of the Internet of Things. The main task of the Internet of Things is to create a single network that includes objects of the information (virtual) and physical (real) worlds and will ensure the interaction of objects with each other.

The technological base of the first stage of development of the Internet of Things is all-pervasive (wireless) sensor networks, which are widely used in the modern world in almost all spheres of life, due to their low cost, rapid deployment and efficiency.

The implementation of the concept of the Internet of Things is expressed in the penetration of telecommunication technologies into all spheres of human activity. Currently, this is reflected in the expansion of the field of application of wireless sensor networks.

The concept of the Internet of Things includes data exchange between devices (M2M), sensor networks, and self-organizing networks of mobile devices (MANET). This article provides an overview of the main methods for calculating the topology of self-organizing networks.

The task of improving the quality of data transmission in self-organizing networks of mobile devices can be solved by different methods: the method of retransmission request (ARQ) [18], the method of redundant coding (FEC) [5, 9, 13, 26, 40, 52, 61], the method of Network Coding [14]. One of the approaches to data transmission in self-organized networks is the use of the method of superimposed networks (P2P) [36, 54]. P2P protocol sets the rules for streaming data between nodes [6, 11, 31, 42, 46]. Streaming data is transmitted between the nodes of the superimposed network along the routes selected by the underlying protocols [19, 20]. Controlling the data transmission process will avoid congested areas in the network, increase the throughput and improve the reliability of the network as a whole [2, 3, 24, 43, 60, 62]. Overlay networks rely on tree and multi-link structures [12, 16, 71]. To improve network reliability, some researchers [44] use different types of multipath redundancy, such as “routing braids”, which demonstrate improved reliability and stability in self-organizing networks. The environmental sector demonstrates particular interest in IoT, where modern air quality monitoring systems can be built using sensor networks [28, 29, 53, 67, 69, 70]. Also as a part of complex diagnostic systems of energy facilities [4, 23, 64–66] which build on hierarchical structures, IoT can be used in energy sector.

2. Analysis of routing protocols in IoT systems

Self-organizing networks are an alternative to infrastructure networks. In such a network, each node in the network can act as a router. The possibility for each node to leave the network or connect to it will lead to the fact that an important issue in the organization of the self-organizing network is the choice of a routing protocol. The routing protocols developed are classified according to the approach to update the network topology information into reactive, proactive, and hybrid [7]. Figure 1 shows the classification of routing protocols.

The reactive approach to routing involves constructing routes as they are needed. When a connection to a network node is attempted, a complete enumeration of all options is performed and the best route to it is found according to the routing metric. This route is used as long as there is a connection to the destination.

With a proactive approach, the network topology must be monitored and updated at specific intervals. Proactive protocols update the network topology with periodic queries. Protocols belonging to this group may use different numbers of databases with information about the network topology and different ways of keeping this information up to date. The proactive approach relies on keeping track of the network topology, so nodes are constantly exchanging messages, which can lead to higher power consumption compared to the reactive approach. On the other hand, a node in a network using the reactive approach has to wait for the route

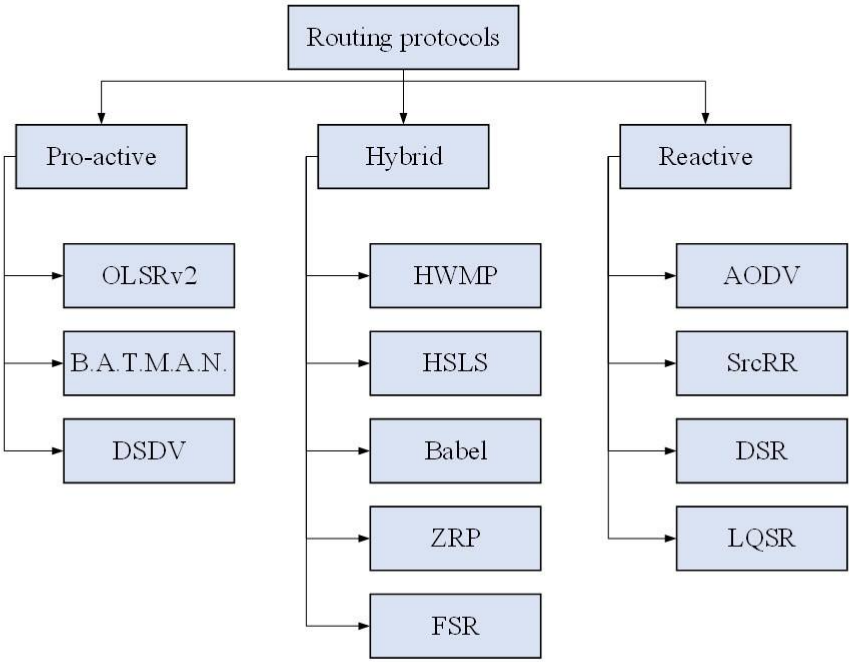

Figure 1: Routing protocols in self-organizing networks.

variants to be enumerated, which can affect the transmission speed in networks with changing topologies. The hybrid approach involves combining reactive and proactive approaches within the same network. The best route between network nodes is selected based on metrics: number of routing steps, ETX, ETT, Air Time Link, etc. Metrics can take into account information from the physical, data link, and network layers of the OSI model.

2.1. Proactive protocols

The OLSR (Optimized Link State Routing) protocol is proactive and oriented for use in large networks with a high density of nodes. Each node uses HELLO broadcast messages that are transmitted at regular intervals to nodes within one routing step. After receiving the HELLO, the destination node tries to establish a two-way connection with the sender node. The number of control messages in OLSR is reduced due to the MPR (Multipoint Relays) approach [17]. In OLSRv2, the exchange of control messages in the network has become more efficient, and the message form itself has been standardized and simplified. OLSR interacts with the network layer by managing routing tables and using IP addresses for packet transmission. The B.A.T.M.A.N. protocol (Better Approach To Mobile Ad hoc Networks) also uses a proactive approach [41], in which all nodes produce an Originator Message (OGM) broadcast. An OGM contains an originator address, a recipient address, and a unique sequential number. Each neighboring node changes the recipient address to its own and sends the message back to the originator. OGM messages do not include any additional information such as QoS metrics and routing tables. The B.A.T.M.A.N. protocol. Has lower non-productive costs in networks with more nodes than the

OLSR protocol. One of the first proactive protocols was DSDV (Destination Sequenced Distance Vector), developed in 1994 [50]. Its main feature was the addition of an ordinal number field in control messages because this bypassed the problem of loops between nodes in the network (Loop free) since each node now knew whether its information about the network topology was obsolete. DSDV proved ineffective in large networks with rapidly changing topologies but influenced the development of other protocols, such as AODV.

2.2. Reactive protocols

Reactive DSR (Dynamic Source Routing) protocol uses a special DSR Options Header Format that can be added to any packet and contains the route from source to destination node [32]. A node can perform a route discovery process to the desired node (Route Discovery) using broadcast messages. The Route Maintenance process is to monitor the link-layer notifications. If a link-layer notification is accepted or node requests are left unanswered, the discovery process is repeated. Disadvantages and advantages of DSR include its reactivity, which reduces the cost of sending control messages but makes it necessary to buffer packets for the duration of route discovery. Besides, the special header format can lead to a large header for small payloads, reducing the efficiency of the network. Further evolution of the reactive approach was the AODV protocol [49]. Instead of relying on the transmission of voluminous headers, AODV reintroduced routing tables that accumulated all the information about the network topology as messages were received from other nodes. To avoid looping, two sequence numbers were introduced, one for the source and one for the destination, allowing you to track the novelty of topology information as you use the route from the destination to the source. The use of AODV is recommended for networks of 10 to 1000 mobile nodes. The main goal of its development was to reduce the cost of sending control messages and to improve the scalability and performance of the network. Another protocol based on DSR was reactive SrcRR [1]. Its main difference from DSR was the use of an ETX metric, which was measured by periodic broadcasts to neighboring nodes, and the total ETX of its parts was used for the entire route. Also, SrcRR was independent of the network layer and could use MAC addresses to find the path. Microsoft developed and patented the LQSR (Link Quality Source Routing) protocol, which is also based on DSR [21]. It is implemented between the link layer and the network layer using a virtual network adapter, allowing it to handle multiple physical connections at once. The LQSR header is located between the Ethernet header and the frame payload. Each node, as in SrcRR, measures the QoS metric to neighboring nodes, propagates this information through the network, and it is taken into account in selecting the best path to the destination. Guided by the rule that the shortest path does not mean the best path, LQSR allows the use of three QoS metrics: ETX, RTT, and PktPair. VNF sees network latency as a critical attribute for reliability, availability, and QoS requirements by most researchers. By automating and elastically allocating resources, these enhanced service offerings are implemented [39].

2.3. Hybrid protocols

The hybrid approach enables the use of reactive and proactive approaches within a single network. It is used in 802.11s to provide WMN support at the link layer [30, 68]. In previous

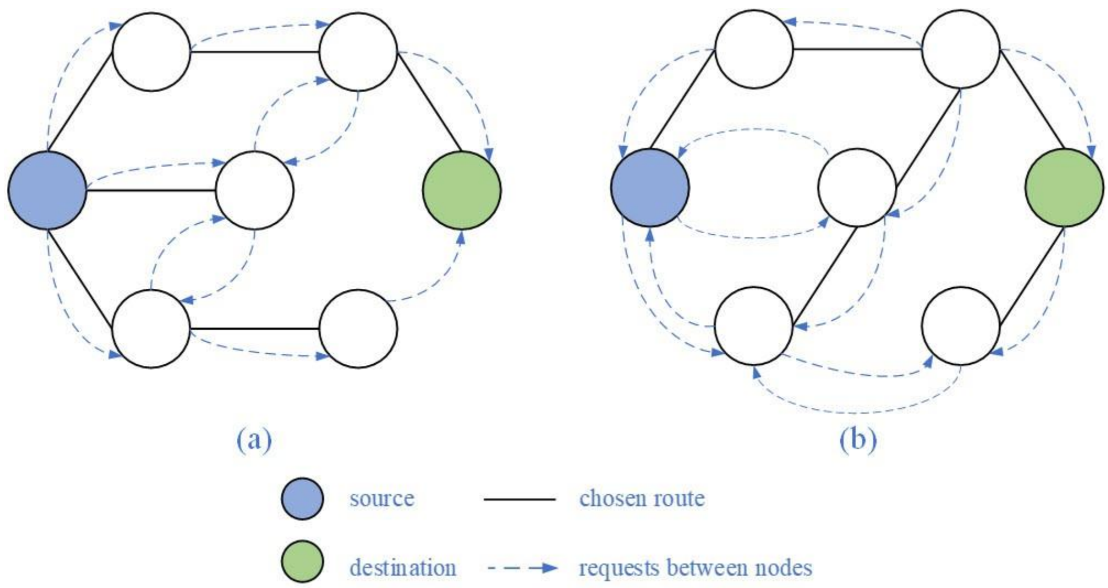

Figure 2: Reactive (a) and proactive (b) modes of the HWMP protocol.

802.11 family standards, there was no way to obtain link-layer QoS metrics. For the QoS metric to be more accurate, it should be obtained at a lower layer of the OSI network model. As a default protocol in the standard 802.11s recommended hybrid HWMP (Hybrid Wireless Mesh Protocol), and the optional protocol can act as OLSR. The reactive approach is implemented based on AODV (Ad hoc On-demand Distance Vector). In this case, the node looks for the best route as needed, taking into account QoS metrics. Using a proactive approach, a root node (Root) is assigned to a WMN that polls nodes at intervals, thus updating the network map. The connected node, can contact the root node and get information about the routes to all nodes in the network. Both approaches can be used separately or simultaneously in the same network (figure 2).

The hybrid approach has been used not only in HWMP but also in earlier protocols, such as the HSLS (Hazy Sighted Link State) Routing Protocol. Intending to reduce non-productive costs, HLSL controls the interval at which network topology information is updated to reduce the number of control messages [56]. If the route is obsolete, HLSL begins to operate in reactive mode. The lack of up-to-date network topology information is a major drawback of this protocol. Another hybrid protocol for WMN is Babel. Based on the ideas of DSDV, AODV, and the Cisco EIGRP (Enhanced Interior Gateway Protocol), Babel takes a proactive approach and is aimed at working in networks with mobile nodes [15]. It allows the implementation of different QoS metrics, although by default it uses ETX. Reactive mode is used in Babel if no route from a node is suitable for reliable packet transmission. In a hybrid protocol, ZRP (Zone Routing Protocol) node applies proactive route lookup within a certain section of the network and reactive outside of it [27]. The FSR (Fish-eye State Routing Protocol) protocol is characterized by the fact that the accuracy of the network topology information decreases with distance from the node [48].

3. Analysis of data transmission methods and correction of transmission errors

3.1. Retransmission request method

Many different methods are used to recover lost and corrupted data. In self-organizing networks, the network topology and transmission environment change rapidly, it is very difficult to ensure reliable communication, to overcome the high mobility of nodes and external interference. Therefore, many packets are received with errors, which means that error correction methods play a significant role in data transmission processes [59].

In the transmission error correction method with a repeated request (ARQ), data reception acknowledgment messages (ACK) are used for reliable data transmission. For example, if the source has not received an acknowledgment from the recipient within a certain time interval (timeout), it will retransmit until it receives an ACK message. The ARQ method relies on sum and sequence number check fields in each packet header to detect corrupted and retransmitted data. The retransmission request is used in the Stop-and-Wait ARQ, Go-Back-N ARQ, and Selective-Repeat ARQ methods.

The Stop-and-Wait ARQ and Selective-Repeat ARQ methods are used in the 802.11 families of standards at the data link layer of the OSI model, and all three approaches are used in various transport layer protocols. The methods differ in the size of the transmit window and the receive window. The Stop-and-Wait ARQ method starts a timer for each packet that is sent, and the source waits until the ACK message arrives. If the ACK message has not been received and the timeout has already expired, the source will repeat the packet. Thus, the interaction between source and destination occurs from packet to packet.

The Go-Back-N ARQ method is more efficient than Stop-and-Wait ARQ. With this approach, the source transmits several packets at a time and stores them in a buffer until it receives a group ACK message. After the timeout expires, the source repeats all packets for which no ACK message arrived. The Stop-and-Wait ARQ and Go-Back-N ARQ methods are very similar, but they use different transmit window sizes.

In the Selective-Repeat ARQ method, the source transmits several packets at once but waits for an individual acknowledgment for each packet. The receive and transmit windows sizes are the same, and the destination can receive and store packets received in any order. The source repeats those packets for which the timeout has expired.

The ARQ method can improve connection reliability but is not suitable for use in video broadcasting because of the large and unstable delay.

3.2. Direct error correction method

The FEC method adds redundancy to the data being sent, which allows the addressee to detect and correct errors without a second request from the source, and the maximum number of bits recovered depends on the code used. The FEC method is usually implemented at the physical layer and is responsible for correcting errors caused by interference in the communication channel. The application layer FEC method uses Reed Solomon codes or BCX codes. By introducing redundancy, this code can detect and correct bit errors in transmission. But the introduction of redundancy reduces the efficiency of communication channels if the transmission is error-free. Therefore, an adaptive noise coding method has been developed [33, 47, 55, 57]. This method allows controlling redundancy at byte or packet-level [34, 37], using video characteristics or quality of service metrics, such as information fragment delivery ratio.

3.3. Network coding method

One method that is very similar to the FEC method is network coding (NC) [25]. In the NC method, data are encoded by intermediate nodes. The self-organizing network provides new opportunities for the implementation of the NC method. Today, the NC method for reliable video data transmission is most often implemented based on random linear network coding (RLCN). The source node groups the data into generations encodes each generation with SLSC and writes the encoding coefficients in the header of each packet. In the NC method, redundancy can be controlled: k line-independent packets of a given generation are required to decode all packets of the same generation. Thus, more encoded packets can be transmitted in unreliable transmission channels. SLSC has advantages over other coding methods (e.g., fountain code, block code) in that it makes the handling of encoded packets more flexible, reduces the network delay for video transmission, eliminates the transmission of identical packets, and uses the bandwidth more efficiently. The SLSC method can be used in conjunction with the ARQ method to prevent the loss of the entire packet generation. Packets needed for decoding the current generation can be requested from neighboring nodes to obtain k line-independent packets of each generation. The SLSC method has much in common with FEC coding, but FEC is implemented only on the destination node, while the SK method is also implemented on the intermediate nodes. FEC and SK methods can work simultaneously without additional modifications, but more complex hybrid solutions are possible. The SK method can improve network reliability and resilience when used in conjunction with the multipath redundancy method.

3.4. Multipath redundancy method

The multipath redundancy method is to transfer data from the source to the destination via multiple routes. This method of routing has different goals: to distribute the load on the network routes or to increase the bandwidth and reliability of the network as a whole [35, 45]. Applying the multipath redundancy method, it is possible to get rid of congested sections in the network or simultaneously deliver streaming data via multiple routes. However, a self-organizing network is usually congested at the section between the source and the destination, and its network topology is inconstant and therefore requires recalculation of independent routes. It is because of this that multipath redundancy is more often used to improve network reliability. Multipath redundancy can be provided by a superimposed network [8, 10]. The simplest structure of a superimposed network is a single-layer tree. The root of such a tree is the source node. The short existence time of a connection between nodes imposes restrictions on the application of this structure in a self-organizing network. A multi-layer structure can also be used in superimposed networks. This structure is more resilient to user outages, the load is evenly distributed throughout the network, and does not require centralized coordination, both during normal network operation and during emergencies. The structure is adapted both for single-source transmissions and to provide transmissions from multiple sources. The disadvantage of this structure is that the networks built on their basis are more complex than their counterparts. This entails that to maintain this structure, a large volume of control messages are transferred between the nodes of the network. This can significantly limit the applicability of such a structure to nodes that vary considerably in self-organizing networks. The multilayer tree structure seeks to eliminate two major drawbacks of an overlapping network with a single-tree structure [22]. First, in single-tree structures, the few closest nodes are loaded much more heavily than the rest of the network, since the "leaves" of the tree have not been involved in content transmission. Secondly, the disconnection of these highly stressed nodes leads to mass switching of network users looking for a new data source and a new connection point. Node outages could lead to the degradation of streaming data quality. In a multilayer tree, each node must stream data in multiple trees with a common root, distributing complimentary content. Such a structure ensures that all content is not lost if one of the trees loses connectivity and better utilizes the available resources of each node in the network. Source S distributes streaming data to all nodes at once, but some video (e.g., every third fragment) can be transmitted along the intended paths between the nodes themselves. Thus, instead of a single tree, we consider three single-layer trees at once in the case of a multilayer tree with a multilayer coefficient equal to three [51]. To improve network reliability, some algorithms use different types of multipath redundancy, such as multipath "braid" routing. This move allows the use of multiple routes instead of a single route to apply the SC method, which improves the reliability and robustness of self-organizing networks [44]. The multilayer tree structure helps to overcome packet loss in multicast in case of multiple node outage [58]. But the use of multiple paths can increase the unproductive cost of forwarding data, so more research on this method is needed. The multilayer tree structure can be combined with SC, FEC, and ARQ methods to improve data transmission efficiency [38].

4. Conclusions

Known routing protocols used in self-organizing networks are considered and analyzed. The main disadvantage of existing routing protocols is that they cannot respond to abrupt changes in the network topology, which entails their inefficiency in self-organizing networks with highly mobile nodes. When a source is broadcast to one destination, the quality of the transmission depends entirely on the performance of the routing protocol. In the event of loss of one route due to movement of one or more nodes of the network or due to a change in the state of communication channels between nodes, routing protocols cannot effectively use existing routes in the network to transfer streaming data from the source to destination. An overview of transmission error correction techniques has been made and a process for transmitting streaming data using a selective retransmission request method has been described.

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