**目 录**

[摘 要 I](#_Toc71659053)

[ABSTRACT II](#_Toc71659054)

[第1章 绪 论 1](#_Toc71659055)

[1.1 选题背景和研究意义 1](#_Toc71659056)

[1.2 研究现状 1](#_Toc71659057)

[1.3 论文组织结构 1](#_Toc71659058)

[第2章 OLSR原始协议 2](#_Toc71659059)

[2.1 OLSR协议基本介绍 2](#_Toc71659060)

[2.2 OLSR的数据结构 2](#_Toc71659061)

[2.2.1 链路码（LinkCode） 2](#_Toc71659062)

[2.2.2 邻居码（NeighCode） 2](#_Toc71659063)

[2.2.3 邻居状态码（NeighStatus） 2](#_Toc71659064)

[2.2.4 消息类型码（messageType） 2](#_Toc71659065)

[2.2.5 链路类型消息（link\_status） 3](#_Toc71659066)

[2.2.6 邻居类型消息（neigh\_status） 3](#_Toc71659067)

[2.2.7 HELLO消息（message\_hello） 4](#_Toc71659068)

[2.2.8 TC消息（message\_tc） 4](#_Toc71659069)

[2.2.9 消息包（message\_packet） 4](#_Toc71659070)

[2.2.10 OLSR数据包（OLSR\_packet） 4](#_Toc71659071)

[2.2.11 链路表 5](#_Toc71659072)

[2.2.12 一跳邻居表 5](#_Toc71659073)

[2.2.13 二跳邻居表 5](#_Toc71659074)

[2.2.14 MPR选择集 5](#_Toc71659075)

[2.2.15 重复记录表 5](#_Toc71659076)

[2.2.16 拓扑表 5](#_Toc71659077)

[2.2.17 路由表 5](#_Toc71659078)

[2.3 OLSR算法 5](#_Toc71659079)

[2.4 MPR算法 5](#_Toc71659080)

[2.5 OPNET介绍 5](#_Toc71659081)

[第3章 MPR机制改进 6](#_Toc71659082)

[3.1 MPR冗余分析与改进 6](#_Toc71659083)

[3.2 链路质量评估 6](#_Toc71659084)

[3.2.1 传输距离 6](#_Toc71659085)

[3.2.2 传输延时 6](#_Toc71659086)

[3.2.3 信噪比 6](#_Toc71659087)

[第4章 仿真结果分析 7](#_Toc71659088)

[4.1 仿真实现 7](#_Toc71659089)

[4.2 结果分析 7](#_Toc71659090)

[第5章 结束语 8](#_Toc71659091)

[5.1 本文总结 8](#_Toc71659092)

[5.2 工作展望 8](#_Toc71659093)

[致 谢 9](#_Toc71659094)

[参考文献 10](#_Toc71659095)

[附录1 代码及相关附件 11](#_Toc71659096)

[附录2 文献英文原文 12](#_Toc71659097)

[附录3 文献中文译文 19](#_Toc71659098)

**基于链路质量的OLSR自组网路由改进方案**

# 摘 要

无线自组织网（Ad Hoc）是一种不局限于特定的基础设备，可以随时随地快速构建的多跳临时性无中心网络，相较于传统的无线网络，无线自组织网的每一个节点均具有路由功能，而不依赖于传统无线网中的专用路由设备。对于无线自组织网络，路由协议决定了无线自组织网络邻居发现、拓扑建立的速度以及控制数据包广播和业务数据包转发的效率。

目前常见的路由协议主要分为按需路由（AODV，DSR），先验式路由（OLSR，DSDV），混合式路由（TORA，ZRP）。由于目前主流的无线自组织网络的路由协议比较成熟，所以本文主要是在简易实现OLSR的基础上，针对OLSR的MPR计算和Willingness更新策略进行改进实现。原始OLSR的MPR计算存在冗余，并且未考虑Willingness的初始值以及更新策略，本文将通过改变贪心策略尝试减少MPR计算产生的冗余，在此基础上，通过计算节点的传输延时、邻居距离、传输信噪比等表示链路质量的特性动态更新节点的Willingness，使得无线自组织网络可以考虑物理层特性来构建网络拓扑和路由。

OPNET是通信研究领域使用较为广泛的网络仿真软件，本文将使用OPNET来模拟现实使用环境，测试改进的效果。

**关键词：**无线自组网路由协议；OLSR协议；链路质量

# ABSTRACT

Ad Hoc is a kind of multi-hop temporary non-centralized network that is not limited to specific basic equipment and can be quickly constructed anytime and anywhere. Compared with the traditional wireless network, each node of the wireless ad hoc network has routing function, and it does not rely on dedicated routing equipment in traditional wireless networks. For wireless ad hoc networks, the routing protocol determines the speed of wireless ad hoc network neighbor discovery, topology establishment, and the efficiency of controlling data packet broadcasting and service data packet forwarding.

At present, common routing protocols are mainly divided into proactive routings (AODV, DSR), reactive routings (OLSR, DSDV), and hybrid routing (TORA, ZRP). As the current mainstream wireless ad hoc network routing protocol is relatively sophisticated, this article is mainly based on the simple implementation of OLSR, and improves OLSR's MPR calculation and Willingness update strategy. The MPR calculation of the original OLSR is redundant, and does not consider the initial value of Willingness and its update strategy. This article will try to change the greedy strategy to reduce the redundancy generated by the MPR calculation. On this basis of that, the Willingness of the node will be dynamically updated by calculating the transmission delay of the node, the neighbor distance, transmission signal-to-noise ratio and other characteristics which indicate link quality, so that the wireless ad hoc network can consider the physical layer characteristics to construct the network topology and routing.

OPNET is a widely used network simulation software in the field of communication research. This article will use OPNET to simulate the actual use environment and test the effect of improvement.

**Keywords:** Ad Hoc routing protocols; OLSR protocol; Quality of Link;

# 

# 绪 论

## 选题背景和研究意义

随着通信技术和计算机科学技术的进步，无线通信技术快速增长，并在各行各业中得到了广泛的使用。传统的移动通信网络例如手机网络，家用无线网络等一般具有中心节点，例如AP，移动基站等设施。中心节点具有路由功能，其他节点通过中心节点转发业务数据。但是有中心网络在战场，城市消防，灾后救援等场景下不能很好的发挥作用，特别是当中心节点瘫痪之后，整个网络将无法工作。

无线自组织网络（以下简称无线自组网）不局限于特定的基础设备，不依赖中心节点，可以随时随地快速构建，这很好的解决了传统网络在上述场景下的应用缺陷。

无线自组网起源自分组无线网(Packet Radio Network)，其因为军事通信的需要而产生。1991年，IEEE802.11标准委员会采用“Ad Hoc网络”描述这种特殊的对等式无线移动网络。

## 研究现状

## 论文组织结构

本文将简单介绍无线自组网和路由协议的背景知识，详细介绍OLSR的协议内容，例如数据结构和具体算法。在OLSR协议的基础上，本文将说明OLSR的部分缺陷，以及设计的改进方案。最后，本文将对基于OPNET得到的仿真结果进行分析，评估设计方案的效果。

# OLSR协议

## OLSR协议基本介绍

## OLSR的数据结构

本文设计的数据结构源自于OLSR RFC 3626技术文档[[[1]](#endnote-1)]，根据具体实现对部分数据结构进行了拆分和简化。

### 链路码（LinkCode）

链路码是HELLO消息中表示链路状态的标识码，分为以下三种：

AYSM\_LINK：表示对应的链路是单向可达链路（在当前时间，仅有一方可以确认该链路有效）。

SYM\_LINK：表示对应的链路是双向可达链路或者堆成链路（在当前时间，双方均能确认这条链路有效）

LOST\_LINK：表示对应的链路已经失效（在当前时间，链路无效，主要是反馈无效的链路以更新链路表）。

### 邻居码（NeighCode）

邻居码是HELLO消息中表示邻居状态的标识码，分为以下三种：

NOT\_NEIGH：表示对应的节点已经不属于发送节点的邻居。

SYM\_NEIGH：表示对应的节点是发送节点的对称邻居。

MPR\_NEIGH：表示对应的节点属于发送节点的MPR生成集。

### 邻居状态码（NeighStatus）

邻居状态码表示记录在一跳邻居表中的邻居的状态。

NOT\_SYM：表示对应的邻居表中表项的邻居不是对称邻居。

SYM：表示对应的邻居表中表项的邻居是兑成邻居（包含SYM和MPR类型）。

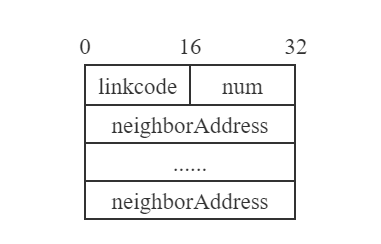
### 消息类型码（messageType）

消息类型主要分为业务消息和控制消息，业务消息并没有特殊的格式，只要符合消息包的格式即可，控制消息主要分为两类，负责链路侦听和邻居发现的HELLO消息、负责全局拓扑广播的TC消息。消息类型码是为了区分不同的控制消息。

HELLO：HELLO消息。

TC：TC消息。

### 链路类型消息（link\_status）



**图2‑1 链路类型消息格式**

链路类型消息向其他节点说明了发送节点周围的链路状态。图2‑1 **链路类型消息格式**是链路类型消息的格式。

linkcode表示下面的neighborAddress和发送节点之间的链接均是linkcode对应的链路码。num是neighborAddress的数量，为了方便发送前组包和接收后解包。

### 邻居类型消息（neigh\_status）

图片包含 应用程序

描述已自动生成

**图2‑2 邻居类型消息格式**

邻居类型消息向其他节点说明了发送节点周围的邻居关系。图2‑2是链路类型消息的格式。

neighcode表示下面的neighborAddress是均是发送节点的邻居，对应的邻居码是neighcode。num是neighborAddress的数量，作用同2.2.5中的num。

### HELLO消息（message\_hello）

表格

描述已自动生成

**图2‑3 HELLO消息格式**

HELLO消息携带了发送节点的链路信息和邻居关系，用于和接收者交换信息，实现链路侦听和邻居发现。图2‑3是HELLO消息的格式。

willingness是节点愿意为其他节点转发数据包的意愿程度，本文将其划分为七个程度：WILL\_NEVER，WILL\_LOWER，WILL\_LOW，WILL\_DEFAULT，WILL\_HIGH，WILL\_HIGHER，WILL\_ALWAYS。每个节点的初始值为WILL\_DEFAULT，节点的willingness将根据网络的变化而动态变化，其变化算法将在第3章中描述。

### TC消息（message\_tc）

### 消息包（message\_packet）

### OLSR数据包（OLSR\_packet）

### 链路表（local\_link）

### 一跳邻居表（one\_hop\_neighbor）

### 二跳邻居表（two\_hop\_neighbor）

### MPR选择集（MPR）

### 重复记录表（duplicate\_set）

### 拓扑表（topology\_item）

### 路由表（route\_item）

## OLSR算法

## MPR生成算法

## OPNET介绍

# MPR机制改进

## MPR冗余分析与改进

## 链路质量评估

### 传输距离

### 传输延时

### 信噪比

# 仿真结果分析

## 仿真实现

## 结果分析

# 结束语

## 本文总结

## 工作展望

# 致 谢

# 参考文献

# 附录1 代码及相关附件

# 附录2 文献英文原文

MAC-Layer Anycasting in Ad Hoc Networks

Romit Roy Choudhury and Nitin H. Vaidya

Abstract- A wireless ad hoc network is formed by a group of wireless hosts, without the use of any infrastructure. To enable communication, hosts cooperate among themselves to forward packets on behalf of each other. A key challenge in ad hoc networks lies in design efficient routing strategies. While several routing protocols have been proposed, most of them aim to select one optimal route between the source and destination. The MAC layer at each intermediate node is then required to forward packets to the next downstream node on that route. We argue that choosing a single optimal route at the network layer may not be sufficient. Knowledge of short-term channel conditions at the MAC layer can play an important role in improving end-to-end performance. Instantaneous interference, channel contention, power constraints and other considerations may be taken into account along with the network layer’s long-term view. This paper proposes MAC-layer anycasting – a forwarding strategy that combines the guidelines from the network layer, with MAC layer knowledge of the local channel. We describe some applications of MAC-layer anycasting, and discuss the performance related tradeoffs.

I. INTRODUCTION

Wireless Ad hoc networks are infrastructureless multi-hop networks in which nodes behave as mobile routers. Routing protocols attempt to choose “optimal” routes based on some optimality criteria (e.g., number of hops). However, in the process of selecting an optimal route, the routing protocol is often faced with the decision to choose between two equally good routes. Ties are often broken randomly. MAC-layer anycasting is a proposal that aims to utilize the knowledge of instantaneous channel condition in selecting the suitable downstream neighbor on shorter time scales. The observation that routes chosen by the network layer are “optimal” on a longer time scale, and ignores the possibility of transient variations in link conditions, motivates our work on MAC-layer anycasting.

The key idea behind MAC-layer anycasting is to achieve the goals of the network layer, while invoking short-term optimizations at the MAC layer, based on local channel conditions. With the proposed approach, the network layer is given the option of specifying multiple downstream destinations to the MAC protocol. The MAC protocol assumes that forwarding the packet to any one of these destinations is acceptable to the routing layer. Depending on the current channel state, the MAC layer then forwards the packet to one of the specified neighbors. Out-of-order packet delivery is a potential problem with proposed anycasting. We discuss this, and other tradeoffs associated with anycasting, later in the paper.

II. PRELIMINARIES

Routing protocols can be broadly classified into “source routed” or “table-driven” protocols. In source routing, the sender of a packet completely specifies the route that the packet must traverse to reach its final destination. Johnson et al. proposed dynamic source routing (DSR) in which the sender node floods a route request (RREQ) probe in search of a route to the destination. Intermediate nodes that forward this request probe, append their identifiers to the probe. The probe that arrives first at the destination is assumed to have arrived on the optimal path. DSR uses this path for subsequent communication.

Table-driven routing protocols store routing information locally. Nodes exchange routing messages, either reactively or periodically, to update each other about the status of links in the network. When a node intends to send data packets to another node, it consults its routing tables for a route to the destination. It forwards the data packet to the appropriate neighbor in the route, who in turn consults its own tables to forward the packet further. An intermediate node is often faced with the decision to choose between two of its neighbors, both of which may be equally good for forwarding the packet to the final destination. Ties are broken randomly, without respecting the possibility that one of the nodes may not be suitable for immediate transmission. We believe that anycasting can be useful here – the MAC layer can make educated decisions in such scenarios, leading to potential benefits in performance. In this paper, we would refer to table driven protocols while discussing the details of MAC-layer anycasting. Issues arising from the use of source routing will be discussed separately in Section V.

Roy et al. propose the notion of maximally zone disjoint routes. Based on previous traffic conditions, a sender selects routes that can maximally bypass congested regions. Our idea of anycasting differs from in the sense that we base our forwarding decisions on factors that vary on a shorter time scale. The routing layer only provides a set of acceptable options (not all of which may be optimal). The MAC layer then chooses the next hop depending on the instantaneous network condition. Pursley et al. proposed the idea of using “decoder side information” to aid forwarding decisions. By observing the number of correct symbols received (from a sequence of known transmitted symbols), the receiver may be able to estimate, statistically, the reliability of the link. The authors propose a metric, resistance, which is indicative of link quality. Using this metric, a node examines two outgoing links, and transmits the packet over the one with lower resistance. While this scheme handles variation in channel fluctuations, it does not consider issues related to the MAC layer. MAC-layer anycasting adapts to several MAC protocol constraints, as detailed in the rest of the paper.

Larsson presents the idea of “selection diversity forwarding”, in which a transmitter includes a multicast address (or a list of addresses) in the data packet. Neighbors of the node that are included in the multicast group (or the address list), reply to the packet serially with an ACK packet. The transmitter chooses one of its neighbors, based on the guidelines of the routing layer and the current link conditions learned from the data-ACK exchange. A “forwarding order” is now transmitted to the chosen neighbor, requiring it to forward the packet further. The chosen neighbor replies to the “forwarding order” with a “forwarding order ACK”. Clearly, waiting for all the replies before initiating the “forwarding order” may be wasteful. Jain et al. propose an improvement on the protocol in [9]. The authors propose to specify the list of addresses (similar to [9]) in order of priority. The protocol requires all nodes, included in the address list, to reply in sequence of priority, with the highest priority　first. Upon receiving the first reply (not always from the highest priority node), the transmitter immediately begins data packet transmission to that node. This reduces the overhead associated with waiting for multiple replies before transmitting a packet.　Unlike [9], the order of priority must be specified a priori without knowledge of the instantaneous link conditions. In addition, specifying preferences and multiple addresses increases packet-size, leading to higher control overhead.

Although similar in spirit, MAC-layer anycasting can be distinguished from the body of existing work. The key distinction lies in the basis of decision-making. Observe that most of the previous schemes rely on probing the channel in some form, and choose the suitable neighbor based on explicit or implicit feedbacks. We argue that in several cases, waiting for feedbacks may not be necessary – the MAC layer may already possess necessary information. For example (more examples elaborated later), we observe that the MAC layer may be aware of permissible transmit power-levels at a given point of time. Previous schemes may probe the channel with an impermissible power level, obtain a negative feedback, and converge to the permissible power level. Clearly, using the knowledge available at the MAC layer can be useful in such scenarios. We discuss some wireless medium access control (MAC) protocols next.

We assume that the reader is familiar with the IEEE 802.11 protocol. Briefly, when using 802.11, an exchange of request to send(RTS)/clear to send(CTS) precedes DATA communication. Nodes that overhear the RTS/CTS defer their own transmissions, for the proposed duration of the DATA communication. Once the DATA packet has been transmitted, the receiver replies with an ACK to acknowledge successful reception

Several proposals in the recent past have tuned 802.11. However, the key idea of the protocol remains unchanged. Recently, with advances in antenna technology, several protocols have been proposed that use directional antennas at the MAC layer. The key ideas when using directional antennas may be summarized as follows. Due to the ability to transmit signals in a desired direction, most of the protocols propose to use a combination of directional and omnidirectional RTS/CTS/DATA and/or ACK. Spatial reuse of the channel increases due to reduced interference. The notion of directional NAV enables a node to initiate transmissions that will not interfere with ongoing communication. Range extension, possible due to the higher gain of antenna beams, is an additional benefit – fewer-hop routes can be formed between the source and the destination. Although promising, directional antennas also pose some difficulties. Neighbor discovery, new types of hidden terminals, deafness are some of the problems that arise from directional communication. We believe that anycasting can help, when using directional antennas.

Research on multi-user diversity in medium access control protocols has also been a topic of interest. Qin et al. proposes a channel-aware ALOHA protocol, that schedules transmissions based on instantaneous channel conditions. Using a distributed approach, the protocol requires a node to transmit when its local channel conditions are favorable. Tsatsanis et al. proposed “network assisted diversity protocols”, where the possibility of exploiting corrupted packets has been explored. Put differently, the authors propose the idea of allowing multiple transmitters to collide multiple times (synchronously). From the vector of corrupted packets, the receiver then separates the individual packets, using known signal processing algorithms. DeCouto et al. have recently proposed an ETX metric to favor paths that are characterized by fewer losses and retransmissions. Put differently, while making the routing decisions, the network layer considers the information available at the MAC layer. However, once a route has been chosen, it is used irrespective of the possible changes in instantaneous channel conditions. Yarvis et al. have also proposed similar ideas in the context of sensor networks. The key idea in this paper is somewhat opposite to that of [20], [21]. The MAC layer requires the network layer to supply a set of routes, that it deems suitable. Unlike the above approaches, the MAC layer performs the final decision of choosing the neighbor that appears to be most appropriate at that instant of time.

III. MAC-LAYER ANYCASTING

MAC-layer anycasting can be envisioned as an enhancement to existing MAC and routing protocols. In the rest of this paper, we would call a routing protocol “basic” if it has not been “enhanced” with the anycasting features. One possible architecture to implement MAC-layer anycasting is shown in Figure 1. This section discusses the framework of MAC layer anycasting, in the context of a generic MAC and routing protocol. We also propose a simple variation, named Ordered Anycasting2 . Later, we visit the applications of anycasting and discuss the tradeoffs in the context of wireless ad hoc networks.

The anycast framework requires the “basic” routing protocol to discover/maintain multiple routes for each flow, whenever possible. Clearly, all the discovered routes may not be equally good. When a packet arrives at the network layer, the routing protocol consults the routing state to determine the routes that may be available for the packet’s final destination. From these available routes, the routing protocol selects a subset containing K routes that may be deemed as the best. The network layer now forms what we call the anycast group. The anycast group contains the set of distinct next-hop neighbors, on the selected K routes. As an example, for a packet destined to D, the anycast group specified by the network layer at node S in Figure 2 could be the set (A,X). The packet and the anycast group are then handed down to the MAC layer. Upon receiving the packet, and the anycast group, the MAC layer must select any one suitable neighbor and attempt transmission to it. Instantaneous network conditions may play an important role in determining the selection. The next section presents some of the potential applications of anycasting, and illustrates how the neighbor selection policies may be designed. However, first we propose a simple variation to anycasting, named ordered anycasting.

Ordered anycasting

The routing layer at a node may discover multiple routes to a particular destination. All the routes may not be optimal. For example, if routes R1 and R2 are equally good (e.g., in terms of hop-count), and if both are better than route R3, then the network layer may desire to use R3, only if communication over routes R1 or R2 is currently not possible. Ordered anycasting is a simple variation to anycasting that aims to achieve exactly this. The routing layer ranks the members of the anycast group in order of its preference. The MAC layer attempts communication to a node, only if all other nodes higher in the preference order, have proved to be “unavailable”.

# 附录3 文献中文译文

无线自组网MAC层任播

Romit Roy Choudhury 与 Nitin H. Vaidya

摘要：无线自组网由一组无线主机构成，无需使用任何基础设施。为了实现通信，主机之间相互协作来转发彼此的数据包。无线自组网的关键在于如何设计有效的路由策略。尽管目前已经提出了几种路由协议，但是大部分目的是从源节点到目的节点之间选择一条最优路由。然后每一个中间节点的MAC层需要将数据包转发到这个路由的下一个下游节点。我们认为，在网络层选择一条最优路由可能并不高效。在MAC层中，短期信道状况信息可以有效提高端到端的性能。瞬时干扰，信道争用，功率限制和其他因素可能与网络层的长期视角一同考虑在内。本文提出了MAC层任播，一种结合了网络层规则和MAC层本地信道信息的转发策略。我们描述了MAC层任播的一些应用并讨论了和性能相关的权衡。

一、简介

无线自组网是无基础设施的多跳网络，其中的节点同时作为移动路由。路由协议根据某些最佳标准（例如跳数）选择“最优”路由。但是在选择最优路由的过程中，路由协议往往要在两条同样好的路由中做出选择。链路中的连接经常会随机性中断。MAC层任播目的是在较短时间内利用瞬时信道状况信息来选择合适的下游邻居。我们观察到网络层选择最佳路由的时间更长，并且忽略了链路状况瞬时变化的可能性，这使得我们在MAC层任播上投入了研究。

MAC层任播的关键思路是实现网络层的目标，同时基于本地信道状况在MAC层做短期优化。根据我们提出的方法，网络层可以为MAC层协议提供多个下游目标，MAC层假设路由层可以接受将数据包转发给这些目标的任意一个。根据当前信道的状态，MAC层接下来会将数据包转发给特定的邻居。乱序分组传送是任播的潜在问题，我们将在本文的后面讨论这个问题，并探讨可能的折衷方案。

二、背景

路由协议可以大致分为源路由或者表驱动协议。在源路由协议中，数据包的发送方完全指定了数据包必须经过的路由，数据包才能到达目的地。Johnson等人提出了动态源路由（DSR），发送方泛洪一个路由请求探针（RREQ）来寻找目的地的路由。中间节点转发这个探针，并将自己的标识符加入到探针中。首先达到目的地的探针假定达到了最优路径。DSR将会在后续通信中使用这个路径。

表驱动的路由协议在本地存储路由信息。节点通过反应性或者周期性交换路由消息，来更新网络中链路状态的信息。当一个节点尝试向另外一个节点发送数据包时，它会在路由表中查询目的节点的路由信息。它会将数据包转发给路由中合适的邻居，后者再查询自己的路由表，然后转发数据包。中间节点经常要在两个同样适合向目的节点转发数据包的邻居中做出选择。不考虑其中一个节点不适合立即传输的可能性，链路中的连接往往是随机断开的。我们认为任播对此很有帮助，MAC层可以在此场景下做出明智的选择，在性能上体现出优势。我们将在本文中依据表驱动协议讨论MAC层任播的细节。由源路由引起的问题将在第五章中讨论。

Roy等人提出了最大区域不相交路由的概念。发送方基于之前的流量状况选择最大程度地避开拥挤的区域。我们任播的思路不同于我们基于较短时间内变化因素的转发决策。路由从仅仅提供一组可以接受的选项（并非所有的选项都是最优的）。然后MAC层将根据瞬时网络状况来决定下一跳。Pursley等人提出了使用“解码器辅助信息”来协助转发决策。通过观察从一系列已知的发送信号中正确接收的信号数量，接收器可能能否估计出链路的可靠性。作者提出了一种度量方式，阻力——表示链路的质量。通过这种度量方式，节点可以在两条出战链路中选择较低阻力的链路传输数据包。尽管这种方案处理了信道波动的变化，但是并没有考虑MAC层相关的因素。MAC层任播适应多种MAC层协议约束，这点将在本文下文论述。

Larsson提出了“选择分集转发”，发送器将多播地址（或者地址列表）包含在了数据包中。在多播地址（或者地址列表）中的邻居用ACK包串行答复该数据包。发送器根据路由层的规则和从data-ACK交换中了解到的当前链路状况来选择其中的一个邻居。“forwarding order”被发送到指定的邻居，然后邻居需要将数据包继续转发。选中的邻居需要使用“forwarding order ACK”响应“forwarding order”。显然，等待在初始化“forwarding order”之前的响应是无用的。Jain等人对上述协议提出了一种改进。作者提出要根据优先级指定地址列表（和上述类似）。该协议要求地址列表中的所有节点都按照优先级响应，最高优先级者最先相应。在接收到第一个相应之后（并不一定是最高优先级的节点），发送器立刻向这个节点发送数据包。这样减少了在传输数据之前等待多个响应的开销。与Larsson不同的是，优先级必须提前声明，并且不包含瞬时链路状况信息。另外，指定首选项和多地址会增加数据包的大小，从而产生更高的控制开销。

尽管本质上相似，MAC层任播仍然与现有研究有所区分。关键点在于决策产生的基础。可以看到，大部分以前的方案都用某种形式探测信道，然后根据显式或者隐式的反馈选择合适的邻居。我们认为，等待反馈并不是必须的，因为MAC层可能已经有必要的信息。例如（后面将会展示更多的例子），我们观察到MAC层可能在给定的时间点知道允许的发射功率水平。以前的方案可能会探测到不允许的发射功率水平的信道，然后获得负反馈，再收敛到允许的发射功率水平。显然，使用MAC层上可用的信息在这种情况下会有帮助。我们接下来讨论一些无限媒介访问控制协议（MAC）。

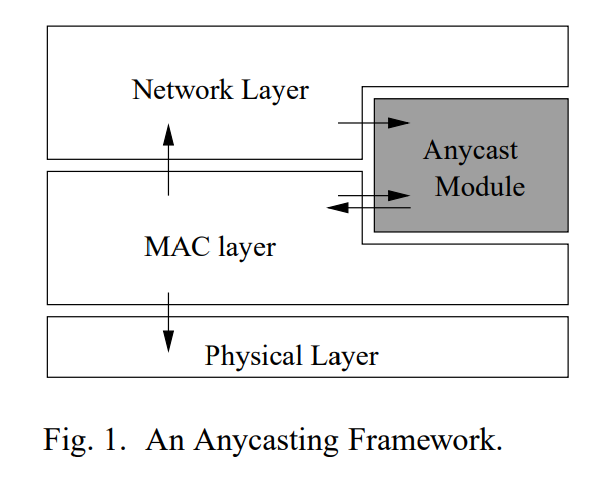
我们假定读者熟悉IEEE 802.11协议。简单来说，当使用802.11时，在数据通信之前，先进行发送请求（RTS）和清楚发送请求（CTS）。侦听到RTS/CTS的节点在已经建立的数据通信持续时间内推迟自己的数据传输。一旦数据包发送了，接收方会回复一个ACK包已确认成功接收。

最近的一些方案对802.11做了一些调整。尽管如此，该协议的基本思想不变。近来，随着天线技术的进步，已经提出了几种在MAC层使用定向天线的协议。使用定向天线的思路可以总结如下。由于具备向期望防线发送信号的能力，大多数协议建议使用定向和全向RTS/CTS/DATA和/或者ACK的组合。信道空间的重用程度将会随着干扰的减少而增加。定向NAV的概念使得节点可以启动新的传输，而不会干扰正在进行的通信。由于天线波束更高的增益，扩大范围是一项额外的益处，源节点和目的节点可以形成跳数更少的路由。定向天线虽然前景很好，但同时也带来一些问题。邻居发现，新型隐藏终端，耳聋是定向通信产生的一些问题。我们认为任播在使用定向天线时可以起到一定的帮助。

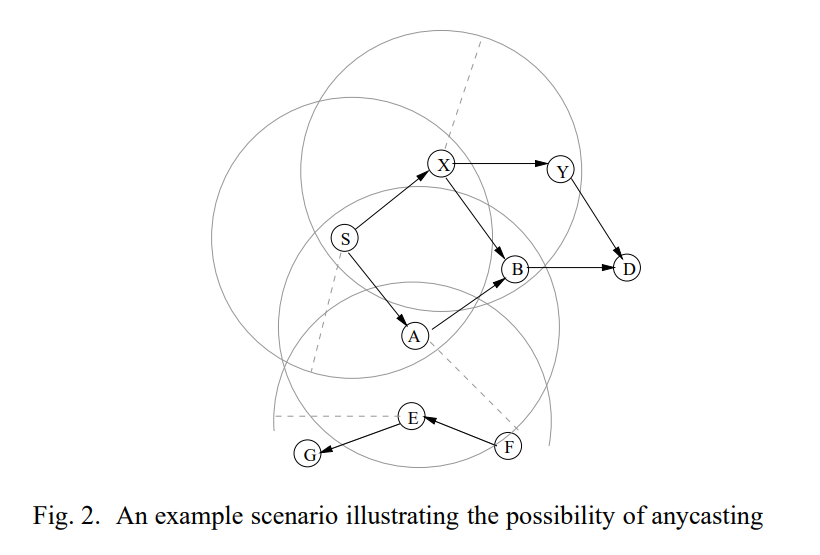
MAC协议中的多用户分集研究也成为人们的研究热点。Qin等人提出了可感知信道的ALOHA协议，该协议瞬时信道状况来调度传输。该协议使用分布式方法，要求节点在其本地信道状况良好的情况下进行传输。Tsatsanis等人提出“网络辅助分集协议”，探讨了利用损坏的数据包的可能性。换句话说，作者提出了允许多个发送器多次（同步）碰撞的思路。然后接收器使用已知的信号处理算法将数据包从损坏的数据包中分离出来。DeCouto等人最近提出了一种ETX度量标准来支持具有较少损耗和重传特征的路径。换句话说，在制定路由决策时，网络层会考虑在MAC层的可用信息。但是，一旦决定了一条路由，便会使用该路由，而不管瞬时信道状况可能的变化。Yarvis等人在传感器网络的背景下也提出了相似的想法。本文的关键思想和DeCouto、Yarvis等人的思想有些相反。MAC层需要网络层提供它认为合适的一组路由。和上述方法不同的是，MAC层最终决定在这个时刻最合适的邻居。

三、MAC层任播

可以将MAC层任播视为对现有MAC和路由协议的增强。在本文的剩余部分，我们将未通过任播功能“增强”的路由协议称为“基准”。图１展示了实现MAC层任播的一种可能的体系结构。本节在通用MAC和路由协议的背景下讨论了MAC层任播的框架。我们还提出了一个简单的变体，称为Ordered Anycasting2。之后，我们将会看到一些任播的应用，并讨论无线自组网中的权衡问题。



任播框架需要“基准”路由协议在可能的情况下发现并维护每个流的多个路由。显然，所有被发现的路由可能并不都是好的。当一个数据包到达网络层，路由协议将查询其路由状态，来决定可以有效到达数据包目的地的路由。从这些可用路由中，路由协议选择包含了K个可能被认为是最佳路由的子集。现在，网络层形成了我们称为任播组的内容。任播组包含了在K个路由上的下一跳的邻居的集合。例如，对于目的地是节点D的数据包，由图２中的节点S所处的网络层指定的任播组可以是集合(A,X)。然后，网络层将数据包和和任播组传递到MAC层。在接收到数据包和任播组之后，MAC层必须选择一个合适的邻居并尝试向其传输。瞬时网络状况可能对决策产生重大影响。下一章介绍了任播的一些可能的应用，并说明了如何设计邻居选择策略。但是首先，我们先对任播进行简单的修改，称之为有序任播。



有序任播

节点的路由层可能会发现到特定目标的多个路由。所有的路由可能不都是最佳的。例如，如果路由R1和R2同样好（例如就跳数而言），并且如果两者均好于R3，那么只有当通过R1或者R2通信不可行的时候，网络层才会选择使用R3。有序任播是为了实现这个目标的任播的一种变体。路由层按照优先级对任播组的成员进行排名。当且仅当其他优先级更高的节点被认为“不可用时”，MAC才会尝试与该节点通信。

1. [] Thomas Clausen, Philippe Jacquet. Optimized Link State Routing Protocol (OLSR)[S]. datatracker.ietf.org 2017, 2017-08-22 [↑](#endnote-ref-1)