

Lessons out of Establishing a Relation between Field Theory and Routing

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Abstract

Despite the existence of hundreds of routing protocols, routing in inter-domain and wireless contexts stills suffer from many problems. To find solutions, investigating relations of routing to other sciences may help. In this report, we therefore propose a to establish a relation from routing to field theory in physics and deduce a number a lessons. The relation leads to a classification of routing protocols schemes and helps to compare different routing protocols. Moreover, the relation reveals fundamental building blocks of routing in particular scenarios and leads to numerous insights for the design of new routing protocols for specific scenarios.

1 Introduction

Today, compute networks as the Internet are in great demand. They enable communication between all participants even over long distances by exchanging data packets. The mechanism for directing logically addressed packets from their source toward their ultimate destination through intermediary nodes is called *routing*. The goal of routing is to find (optimal) paths in a network to forward packets.

Commonly, routing is divided into two functional units: *route establishment* and *packet forwarding*. Route establishment involves the exchange of *connectivity information* between nodes in the network to find routing paths. Packet forwarding relays the packets to their destination using the paths provided by the routing protocol.

To gain insights, we review related concepts in other sciences; particularly the concept of particle in potential field in physics. The general idea to relate route establishment and packet forwarding is as follows: Somehow a physical field is established, e.g. a large electric charge induces an electrostatic field. Then, in the presence of this field, any probe particle moves along the gradients of the field since the field imposes a force. More general, in physics, a field is an assignment of a physical quantity to every point in space and time. The strength of a field usually varies in space and time. Despite the facts that physical fields are usually continuous there are examples where fields are discretized to simplify calculation. An example for this is heat propagation [3]. We argue that this comes very close to what we have when routing an IP packet from one router to another until the packet reaches its destination.

Therefore, in this paper we establish a relation between well-known concept of field theory in physics and routing in IP networks. The purpose of this relation is to motivate a unifying classification and terminology for the numerous IP routing protocols. In addition, this relation reveals a set of fundamental building blocks that give valuable insights for the design and development of routing protocols.

Key to understanding this relation to field theory is to understand that we need to distinguish between the field dynamics itself and the effect of a field on a probe. We argue that field dynamics corresponds to the *route establishment* and the effect of the field on a probe to *packet forwarding* (see Fig. 1).

In the rest of this paper, we first introduce the field construction/route establishment in section 3. Then in section 4 we describe packet forwarding. Following we give some examples on how to embed known routing protocols in the presented theory. Finally, we conclude in section 6.

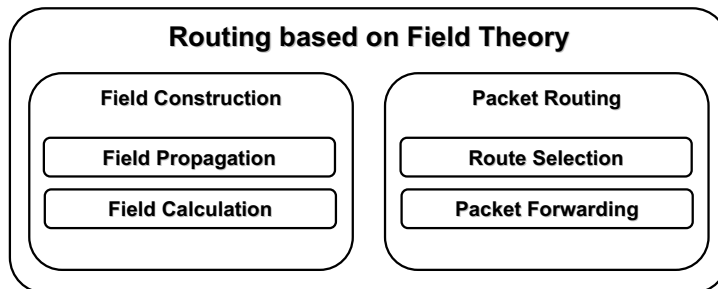


Figure 1: Overview on the relation of field theory and routing

2 Related Work

Today there are a vast of different routing protocols [9, 8, 7]. A very popular classification [8] distinguishes between proactive, reactive, hybrid, hierarchical, geographic and power aware protocols. However, this classification is very limited because it only looks at specific aspects of a routing protocol.

The SECAN lab [7] collected a long list of characteristics of routing protocols. This list allows the engineer to quickly understand the functionality of a protocol. However, this list does not enable any comparisons. Our proposal on establishing a relation to a field theory allows researchers to properly classify and compare routing protocols.

3 Field Construction

The purpose of *field construction* is to prepare all necessary information for *packet routing*. These are namely the exchange of all necessary information using the *field propagation* mechanism and the calculation of the routing field.

3.1 Field Propagation

The purpose of *field propagation* is to exchange the information about the network state Ψ , measured using routing metrics. These metrics can be straight forward as hop count or composed from several routing metrics as ETX, even a network topology. The network state known at a node n is Ψ_n . The information exchange can be done in a proactive, reactive or even hybrid way (see Tab. 1). The propagation range can vary from neighboring up to global.

3.2 Field Calculation

The *field calculation* function f_{calc} uses the network state Ψ_n to calculate a routing field at node n Φ_n . Based on Ψ , f_{calc} calculates a Φ_n spanning the whole network or with a local scope. Φ_n includes the routing information for all destinations. To reduce the field to a single destination, a projection $\langle dest |$ is used (1). With a local scope this could for example be a list of all neighbors and their cost

Routing metric	many	E.g. hop count, signal to noise ratio, bandwidth, delay, neighbors, topology or combinations
Exchange of Ψ_n	proactive	Exchange of Ψ_n in advance of its usage
	reactive	Exchange of Ψ_n upon request
	hybrid	A combination of a proactive and reactive scheme
Propagation range of Ψ_n	global	Ψ_n is propagated all over the network
	local(n)	Ψ_n is propagated locally within a range of n hops
	neighboring	Ψ_n is propagated to the neighbors

Table 1: Characteristics of Field Propagation

to the destination or with a global scope a weighted graph with all paths to a destination. Note that a destination does not have to be a single host, see Tab. 2.

$$\Phi_n = f_{calc}(\Psi_n) \langle dest | \Phi_n \rangle \quad (1)$$

f_{calc}	any	f_{calc} calculates the routing field Φ_n for example shortest path
Scope of Φ_n	global	Φ_n contains complete routes from a source to a destination.
	local	Φ_n contains the information about the next hops towards a destination.
Type of destination	unicast	The destination is one specific host.
	multicast	The destinations are several specific hosts.
	anycast	The destination is one host out of a group of hosts.
	broadcast(dom)	The destinations are all hosts in the broadcast domain dom .

Table 2: Characteristics of Field Calculation

4 Packet Routing

The packet routing is responsible for the handling of the packets. When it relieves a packet it determines the next hops using the *route selection* based on Φ_n . Following the *packet forwarding* forwards the packet to the determined next hops.

4.1 Route Selection

The purpose of the route selection is to determine the next hops of a packet Π using the route selection function f_{select} and the routing field Φ_n . If Π is source routed, for the source node f_{select} returns the routes (P) according to 2. For intermediate nodes, f_{select} returns the next hops based on the routes defined by the source. If Π is hop-by-hop routed, f_{select} determines the routes (P) according to 2 based on Φ_n and Π . In this case (P) contains only of the next hops while for source routing (P) can be whole paths. Thus f_{select} can also be looked at as a projection of Φ_n on Π written as $\Phi_n | \Pi$. Since Π includes the destination this is equal to $\langle dest | \Phi_n | \Pi \rangle$. In other words f_{select} is the function which selects a specific path or next hop for a packet out of all possible paths or next hops. Note that for multicasts or broadcasts (P) contains more than just one next hop.

$$P = f_{select}(\Phi_n, \Pi) \quad (2)$$

Routing mode of Π	hop-by-hop	The route to the destination is determined on every hop, thus every hop decides on the next hop.
	source	The source determines the route to the destination.
f_{select}	any	f_{select} determines the next hop based on Φ_n and Π for example minimum hop count.

Table 3: Characteristics of Route Selection

4.2 Packet Forwarding

The purpose of packet forwarding is straight forward. Based on the next hop(s) given by the route selection, it forwards a packet.

5 Examples

In this section we first present a scheme for classifying routing protocols and apply it exemplarily to some well known protocols.

For classifying a routing protocol according to the introduced field theory for routing, the scheme depicted in Tab. tab:Scheme can be used.

Field Propagation	
Routing metric (Ψ)	any
Exchange of Ψ	[proactive, reactive, hybrid]
Propagation range	[global, local(n),neighboring]
Field Calculation	
f_{calc}	any
Scope of Φ_n	[global, local]
Route Selection	
f_{select}	any
Routing mode of Π	[source, hop-by-hop]

Table 4: Scheme for Routing Protocol Classification

Following we present exemplary classification for AODV (Tab. 5), DSR (Tab. 6), DSDV (Tab. 7), TORA (Tab. 8) and FBR (Tab. 9).

Field Propagation	
Routing metric (Ψ)	hop count
Exchange of Ψ	reactive
Propagation range	global
Field Calculation	
f_{calc}	Bellman-Ford
Scope of Φ_n	local
Route Selection	
f_{select}	minimum hop-count
Routing mode of Π	hop-by-hop

Table 5: Classification Scheme for AODV [4]

Field Propagation	
Routing metric (Ψ)	hop count
Exchange of Ψ	reactive
Propagation range	global
Field Calculation	
f_{calc}	shortest path
Scope of Φ_n	global
Route Selection	
f_{select}	minimum hop-count
Routing mode of Π	source

Table 6: Classification Scheme for DSR [1]

Field Propagation	
Routing metric (Ψ)	hop count
Exchange of Ψ	proactive
Propagation range	global
Field Calculation	
f_{calc}	Bellman-Ford
Scope of Φ_n	local
Route Selection	
f_{select}	minimum hop-count
Routing mode of Π	hop-by-hop

Table 7: Classification Scheme for DSDV [5]

Field Propagation	
Routing metric (Ψ)	hop count
Exchange of Ψ	reactive
Propagation range	neighboring
Field Calculation	
f_{calc}	link reversal (shortest path)
Scope of Φ_n	local
Route Selection	
f_{select}	steepest gradient (any)
Routing mode of Π	

Table 8: Classification Scheme for TORA [2]

Field Propagation	
Routing metric (Ψ)	any (hop count)
Exchange of Ψ	proactive
Propagation range	neighboring
Field Calculation	
f_{calc}	max neighboru(e.g. conductivity)
Scope of Φ_n	local
Route Selection	
f_{select}	steepest gradient (any)
Routing mode of Π	hop-by-hop

Table 9: Classification Scheme for HEAT [6]

6 Conclusion

In this report we introduced a new way of formalizing the mechanism of routing in analogy to field theory in physics.

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A Symbol Table

Table 10 lists the symbols used in the presented report.

Ψ	network state
Ψ_n	network state known at node n
f_{calc}	<i>field calculation</i> function
Φ	routing field
Φ_n	routing field at node n
f_{select}	route selection function
P	routes
Π	packet

Table 10: *Symbol Table*