Quark Routing

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Abstract. With inherent problem complexity, ever increasing instance size and ever decreasing layout area, there is need in physical design for improved heuristics and algorithms. In this investigation, we present a novel routing methodology based on the mechanics of auctions. We demonstrate its efficacy by exhibiting the superior results of our auctionbased FPGA router QUARK on the standard benchmark suite.

1 Introduction

Most typical routers are based on a *sequential* strategy. With this methodology, one of the nets to be routed is chosen first, and is given a path anywhere among the initially unclaimed set of routing resources. Then a second net is routed in the space unused by the first net, and so on, until the last nets must find a path that has not been used by the preceding nets. We feel that the sequential strategy has inherent limitations that impact both solution quality and runtime.

The main contributions of this investigation are a routing methodology based on the mechanics of an auction that supports a simultaneous routing philosophy; and an FPGA router QUARK that implements a version of our methodology. The idea of using an auction for decision-making is not new, and appears with some frequency in the operating systems literature. One particular area is in the allocation of resources in distributed environments. Tasks are given virtual money with which to bid on the various resources in the system. When a resource becomes available, all tasks can bid on that resource. The highest bidder pays for the resource and utilizes it [GAG95].

There are also two similar negotiation-based routers that have some slight resemblance to our methodology—the PathFinder and NC routers [MCMU95, CHAN00]. The routers represent an FPGA as a graph. Initially, each net is assigned an optimal path, even if it conflicts with the paths of other nets. The algorithm iterates until there are no conflicting assignments. The current cost of a shared resource is set to the number of nets that want it. Each net then finds a new shortest path. Because the shared resources become more expensive, nets heuristically end up negotiating an alternate path. Although this process is not dependent on an initial net ordering, it is not a truly simultaneous strategy. In practice, nets are placed down in order of congestion and are typically ripped up in that order if another net overlaps any part of that net's path.

In our methodology, the entire auction of all the routing resources takes place concurrently. This property has led to a different computational model that represents

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a novel approach to performing simultaneous routing. In addition, our negotiation processes are both different and more personalized.

2 Basic FPGA Auction Methodology

The concept of our auction-based routing methodology is straightforward—the pins of an FPGA are resources that can be bid upon by the nets. Each net seeks to control a set of pins that realize a complete detailed route for that net. For discussion ease, we define two terms.

- A *pin-auction* is the local auction of a single specific pin. The auction generally consists of several nets bidding for the right to route on that pin.
- A *chip-auction* is the complete auction process over the entire circuit. Thus, this auction comprises all of the various pin-auctions.

Thus, a run of an auction-based router corresponds to a single chip-auction, where a chip auction consists of collection of pin auctions, one for each pin.

Only one net can win a given pin-auction, and thus have the right to be routed upon that pin. The goal of each net, while working independently of the other nets, is to win sufficient pin auctions to realize its detailed routing. The chip auction completes successfully after all nets have achieved a detailed routing. It is important to stress that all of the pin-auctions are taking place simultaneously. The individual pin-auctions start when the chip-auction starts and finish when the chip-auction completes. This requirement gives quick proof to our claim that QUARK is a simultaneous router.

2.1 Income

The algorithm begins with each net being given an initial allocation of funds. These funds are normally the only source of assets available to a net for bidding on various pin-auctions. An alternative method would have been to have periodic "pay periods" for nets. For example, nets that are losing several pin-auctions could be given extra money. However, it is our experience that routinely adding income to the system merely cause the prices in the pin-auctions to increase and hampers the chip-auction's ability to finish. Thus, we recommend limiting the application of additional funds to extreme cases.

After a net has been given its money, the net then places its initial bids. We view this initial bidding as being a distinct process from subsequent bidding actions. The initial bidding process must select the specific path to realize the net. Subsequent bidding processes generally only require checking of pin-auctions and updating of bids if necessary.

Once each net has placed its initial set of bids, the chip-auction enters its iterative main phase. In each iteration of the main phase, all nets are given an opportunity to place or modify bids in the various pin-auctions as they see fit. The nets make bids in such a way as to eventually claim ownership of pins that realize a complete detailed route. If two or more nets enter a pin-auction, the first net processed with a maximal bid has current control of the pin.